THE CULTURAL HERITAGE OF INDIA

VOLUME VI

SCIENCE AND TECHNOLOGY

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EDITORS

PRIYADARANJAN RAY, M.A., F.N.I.

Late Khaira Professor of Chemistry
University College of Science
Calcutta

AND

S. N. SEN, M.SC.

Formerly Registrar
Indian Association for the Cultivation of Science, Calcutta;
now Professor of History of Science
The Asiatic Society, Calcutta

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PUBLISHER'S NOTE

INDIA is a land of religion but that she also has a rich scientific tradition is now admitted by all scholars. Volume VI of *The Cultural Heritage of India*, which we now present to the public, is a fairly well-connected account of this heritage covering the major branches of science and technology. This volume, entitled *Science and Technology*, contains thirty-two articles contributed by thirty distinguished scientists. Twenty-nine of these articles are new and only three have been taken from the earlier edition of *The Cultural Heritage of India*. Those three too have been updated. We are deeply indebted to the contributors for the trouble they have taken in writing these articles entirely as a labour of love. Some of the contributors are no more with us. The world of scholarship is the poorer by their death.

This volume has had two editors: Prof. Priyadaranjan Ray and Prof. S. N. Sen. The former was concerned with the ancient and medieval periods and the latter with the modern. Unfortunately, Prof. Ray died before completing his work. The entire editorial burden then fell on Prof. S. N. Sen's shoulders. He accepted the responsibility ungrudgingly and brought all his knowledge and experience to bear on the work to make it flawless. He was assisted in this by Swami Viprananda, Mr Jyotirmoy Basu Ray, and Mr A. K. Mukherjee, Registrar of the Institute.

We appreciate the co-operation we received from the staff of Sree Saraswaty Press Ltd., particularly Mr Mihir Majumdar, in the printing of the volume. We also thank Swapna Printing and Binding Works Pvt. Ltd. for the good job they have done in binding the volume. The Titaghur Paper Mills Co. Ltd. manufactured a special type of paper for this volume. We cannot thank them enough for this.

In using diacritical marks where Sanskrit words occur, the practice followed is the same as in the previous five volumes of *The Cultural Heritage of India*. In the case of some of the Arabic and Persian words, however, it has not been possible to follow the system strictly.

Scientific subjects are discussed strictly impersonally. Personal views have no place there. If there are any in these pages they are of the author and not necessarily of the Ramakrishna Mission Institute of Culture.

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ILLUSTRATIONS

MAPS AND DIAGRAMS

*Plates between pages 386 and 387 are by courtesy: Meteorological Survey of India.

a	stands	for	अ	and	sounds	like	*o*	in	c*o*me
ā	,,	,,	आ	,,	,,	,,	*a*	,,	f*a*r
i	,,	,,	इ	,,	,,	,,	*i*	,,	b*i*t
ī	,,	,,	ई	,,	,,	,,	*ee*	,,	f*ee*l
u	,,	,,	उ	,,	,,	,,	*u*	,,	f*u*ll
ū	,,	,,	ऊ	,,	,,	,,	*oo*	,,	c*oo*l
ṛ	,,	,,	ऋ	,,	may be pronounced like *ri*			,,	*ri*ng
e	,,	,,	ए	,,	sounds	like	*a*	,,	c*a*ke
ai	,,	,,	ऐ	,,	,,	,,	*i*	,,	m*i*te
o	,,	,,	ओ	,,	,,	,,	*o*	,,	n*o*te
au	,,	,,	औ	,,	,,	,,	*ou*	,,	c*ou*nt
ṁ	,,	,,	ं	,,	(*anusvāra*) and sounds like *m*			,,	so*m*e
ḥ	,,	,,	:	,,	(*visarga*)	,,	,,	,,	soft, short *h*

' (apostrophe) stands for *s* (elided अ).

ṅ stands for ङ, ñ for ञ, and ṇ for ण; the first is to be pronounced like English *ng* in si*ng*, or *n* in ba*n*k; the second like the *n* in English si*n*ge (a palatal *n*); and the third, the cerebral ṇ, is made with the tongue-tip up-turned and touching the dome of the palate.

c	stands	for	च्	and	sounds	like	*ch*	in	chur*ch*
ch	,,	,,	छ्	,,	,,	,,	*chh*	,,	chur*ch-h*ill
ṭ	,,	,,	ट्	,,	,,	,,	*t*	,,	cur*t*
ṭh	,,	,,	ठ्	,,	,,	,,	*th*	,,	por*t-h*ole
ḍ	,,	,,	ड्	,,	,,	,,	*d*	,,	bir*d*
ḍh	,,	,,	ढ्	,,	,,	,,	*dh*	,,	bir*d-h*ouse
t	,,	,,	त्	,,	,,	,,	*t*	,,	pa*t* (Italian *t*)
th	,,	,,	थ्	,,	,,	,,	*th*	,,	hi*t-h*ard
d	,,	,,	द्	,,	,,	,,	*d*	,,	ha*d* (Italian *d*)
dh	,,	,,	ध्	,,	,,	,,	*dh*	,,	ma*d-h*ouse
v	,,	,,	व्	,,	,,	,,	*v* or *w*	,,	le*v*y, *w*ater
ś	,,	,,	श्	,,	,,	,,	*sh*	,,	*sh*ip
ṣ	,,	,,	ष्	,,	,,	,,	*sh*	,,	*sh*ould

In connection with the hints on pronunciation and spelling, the following points should also be noted:

(1) All Sanskrit words, except when they are proper nouns, or have come into common use in English, or represent a class of literature, philosophical system, or school of thought, are italicized.

(2) Current geographical names and all modern names from the commencement of the nineteenth century are given in their usual spelling and without diacritical marks.

PREFACE

IN *The Cultural Heritage of India* first published in 1937 as Sri Ramakrishna Centenary memorial, India's contributions to science, both past and present, were confined to a small section—Section III of Volume III. Only nine articles were devoted to the subject covering the following areas: science and religion, Hindu astronomy, Vedic mathematics, mathematics in modern India, the spirit and culture of Āyurveda, botany in India—past and present, India's contribution to chemical knowledge, India's contribution to modern physics, and the scope and achievements of Hindu astrology. When the revised edition of the *Heritage* was planned to comprise several volumes to take stock more fully of India's contributions in various fields of intellectual activity, science was planned initially to be disposed of by a few articles, as in the first edition, to form a small part of one of these volumes. As the search of scholars and the preparation of articles progressed, it became soon apparent that the original plan of a few articles stowed away in an inconspicuous part of a volume would hardly do justice to India's remarkable heritage in science and technology during the ancient, medieval, and modern periods. The result is the present volume in which an attempt has been made to present the growth of science and technology during these three historical periods.

The volume has been divided into two parts—Part I dealing with the ancient and medieval periods, that is, from prehistoric times up to A.D. 1800; and Part II with the modern period from A.D. 1800 onwards. Regarding the latter, a problem arose as to what should be taken as the terminus ad quem. The year of independence was the obvious choice inasmuch as the very character and range of science underwent a profound change after independence compared to what prevailed during the colonial period. So, the story of most of the scientific activities which started prior to 1947, i.e. during the nineteenth century and the early part of the twentieth, has been carried up to independence, with minor adjustment of data for the post-independence era. But in a few areas like atomic and nuclear energy, space, etc. in which the main thrust was after 1947, attempt has been made to incorporate major post-independence developments. Without these transgressions our account of the modern period would not have been realistic.

A more or less common pattern has been followed in the selection of subjects for the two parts, namely, exact sciences—mathematics, astronomy, physics, and chemistry; bio-sciences—botany, zoology, and medicine; earth sciences; and technology—agriculture having been treated as part of technology. Three

of the articles published in the first edition of the *Heritage*, namely, 'Vedic Mathematics' by the late Bibhutibhusan Datta; 'Botany in India—Past and Present' by the late Girija Prasanna Majumdar; and 'Astronomy in Ancient India' by the late P. C. Sen Gupta, have been reprinted in Part I of this volume. The story of mathematics has, however, been completed by a supplementary account of post-Vedic mathematics up to the end of the medieval period, and for astronomy, in which P. C. Sen Gupta finished off with Bhāskara I, a separate paper had to be added to cover the medieval period after Bhāskara I, on which a considerable amount of work has recently been done. Part I also includes several new areas such as physics and mechanics, zoology, mining, shipbuilding, and engineering and architecture. A new comprehensive article on Āyurveda has also been added. The general characteristics of science in this period—its internationalism and its strength through cross-culture interchange—have been emphasized through the last article of this Part.

The late Prof. P. Ray, one of the editors of this volume, before he was incapacitated by age, edited most of the articles of Part I with meticulous care, besides contributing his own papers on chemistry and zoology. We place on record our deep appreciation of his valuable contributions.

The modern period, it is needless to say, is fraught with problems different from those typical of the ancient and the medieval periods. Unlike Europe, modern sciences did not develop in India from her traditional sciences. These sciences arrived in India with the European Jesuit missionaries, fortune-seekers, and colonists from the eighteenth century and from still earlier times. They included medical men, naturalists, engineers, mathematicians, botanists, and the like. The Jesuit missionaries, for example, started their activities soon after the establishment of their mission under S. Francis Xavier. Although they were primarily interested in proselytizing activities, they made important contributions to geography, philology, and other areas of study. During the seventeenth and eighteenth centuries, several members of this order --Johann Grueber, Albert d'Orville, Noel, Mandeslo, Pimentel, Calmette, Bucher, Barbier, Boudier, and Joseph Tieffenthaler—determined the latitudes and longitudes of different parts of India from where they operated.

After the British military success at Plassey (1757), the Directors of the Company embarked upon an extensive programme of carrying out trigonometrical, topographical, hydrographic, geodetic, and geological surveys to ensure the military, administrative, and economic control of the subcontinent. In this new endeavour, the established science of astronomy and the rising new science of surveying by trigonometric, geodetic, geological, and other methods were pressed into service, and a new band of young scientists found their life's ambition fulfilled in getting an opportunity to work in a virgin field of unlimited possibilities. In astronomical surveys, Rev. William Smith (*c.* 1775);

Thomas Deane Pearse (1741-89); Ruben Burrow, assistant to Maskelyne, Astronomer Royal, before coming to India; Michael Topping (1747-96), responsible for the foundation of the Madras observatory (1790); and a few others made notable contributions. William Lambton (1723-1823), who studied advanced mathematics under Charles Hutton and followed with interest General Roy's triangulation work in England, successfully introduced trigonometrical survey to India and laid the foundation of the Great Trigonometrical Survey of India in 1818.

As to geological and related studies, the beginnings may be traced to the last quarter of the eighteenth century. Benjamin Heyne, a member of the Society of the United Brothers, wrote voluminous reports from 1795 on the diamond mines of Malavelly and the iron-smelting industries as practised by the inhabitants of Ramanaikapetta near Ellorā. Henry Westley Voysey (d. 1824), a geologist to the Great Trigonometrical Survey and often described as the 'Father of Indian Geology', carried out geological sections between Bombay and Godavari, Agra and Madras, and Calcutta and Agra. The Geological Survey of India was organized as a government department in 1856 after the arrival in 1851 of Thomas Oldham, Professor of Geology in Dublin, President of the Geological Society of Dublin, and a Fellow of the Royal Society of London.

Indian plant and animal life attracted the attention of European naturalists from the seventeenth century. During 1674-75, Henry Van Rheede, the Dutch Governor of Malabar and a naturalist, collected a large number of Indian plants, described and illustrated them with the help of Brahmin and Carmelite assistants, and published the work in 12 volumes from Amsterdam under the title *Hortus Malabaricus* between 1686 and 1703. About the same time (between 1696 and 1705) there appeared from London Leonard Plukenet's works in four volumes, with 454 plants and 2,740 drawings of plants. From Amsterdam was published Professor Nicholas Laur Burman's *Flora Indica*, in which 1,500 Indian plant species were described according to the Linnaean system of classification. Scientific botany in India, however, commenced with John Gerard Koenig, a pupil of Linnaeus, who arrived in India in 1768 to join the Danish mission at Tranquebar, became the 'Hon'ble Company's Natural Historian' (1728) under the Madras Government. Koenig was responsible for the foundation of a Society of United Brothers for the promotion of natural history in India. Some of the members of the United Brotherhood carried on the good work started by Koenig who died in 1785. The most promising among them was William Roxburgh (1751-1815), who became famous for his *Plants of the Coast of Coromandel* (3 volumes—1795, 1802, and 1819), *Hortus Bengalensis* (1814), and *Flora Indica* (published posthumously with additions by Wallich, 2 volumes—1820 and 1824).

Modern zoological researches in India also originated in stray and scattered observations by amateur and trained naturalists on the animal kingdom—elephants, fishes, serpents, mollusc, sponges, birds, and mammals. Before 1780, *The Philosophical Transactions of the Royal Society* was an important medium for the publication of papers on natural history. In the eighteenth century the Dutch naturalists, under the influence of Linnaeus, became interested in Indian ichthyology, and generated a number of important works by continental ichthyologists, Petrus Artedi (Swedish), L. T. Gronow (German), Mark Eliezer Bloch (a Jewish physician), and Compte de Lacepede (French). The example of these pioneers influenced the English doctor Patrick Russell who succeeded Koenig as the Company's Naturalist to the Madras Government. Patrick Russell was particularly noted for his studies on fishes and poisonous serpents. A long line of competent and devoted zoologists from Francis Buchanan, Sykes, McClelland, Blyth, Day, Bryan Hodgson to Hugh Falconer and Proby Cautley raised Indian zoology to international standard.

This brief, partial, and sketchy résumé of the introduction of European sciences to India is intended to emphasize three things: (i) the colonial powers were interested from the very beginning in field sciences designed to advance their imperial, commercial, and economic motives; (ii) research in basic and fundamental sciences like physics, chemistry, mathematics, and astronomy was not encouraged; and (iii) in the mission-oriented science through government departments and establishments, the Indians had no place. For the Survey departments the Court of Directors of the East India Company 'insisted on the secrecy of maps and surveys and restricted the art of surveying to their own covenanted or military servants'. In the Geological Survey the first Indian apprentice (Ram Singh) was recruited in 1873 and two (Kishen Singh and Hiralal) the following year, of whom two retired as sub-assistants. The first appointment of an Indian (P. N. Bose) in a graded post did not take place until 1880. In his presidental address before the seventh annual meeting of the Indian Science Congress in 1920, P. C. Ray made a pointed reference to the studied care with which the Indians were excluded from public service in government scientific departments. In that year eleven establishments employed 194 Europeans and 18 Indians, the salaries of Indian officers being in most cases nearly half of those of the Europeans.

Opportunities of Indians to be involved actively in original scientific investigations by modern European methodologies slowly opened up from towards the end of the nineteenth century with the setting up of laboratories in a few government and private institutions, of which the physical and chemical laboratories of the Calcutta Presidency College and the Indian Association for the Cultivation of Science deserve special mention. Curzon's criticism of University education solely centred round examinations. The Act of 1904 empowering

the universities to engage themselves in higher teaching and research through the institution of professorships and research scholarships and the establishment of modern scientific laboratories paved the way for Indian students to be engaged in original research. In Calcutta, Asutosh Mookerjee established the University College of Science after the model of the Imperial College of Science and Technology in London and about the same time in Bangalore the Tatas founded the Indian Institute of Science after the example of the German Technical Institutes. Other universities—Allahabad, Lucknow, Lahore, Madras, and Bombay—followed suit. Within less than fifty years, following the organization of facilities for research, Indian science came to its own. Its contributions started appearing regularly in standard scientific journals published by learned societies abroad. The Indian physicists, chemists, mathematicians, botanists, zoologists, geologists, and so on organized themselves in professional societies producing their own journals and publications. Between 1914 and 1935, a period of barely two decades, Indian scientists brought into existence a general national forum like the Indian Science Congress Association after the example of the British Association for the Advancement of Science and National Academies and Institutes in the North, East, and South for co-ordination of scientific research. It was, therefore, not an accident that the first half of the twentieth century produced original scientists like P. C. Ray, J. C. Bose, Ramanujam, C. V. Raman, Meghnad Saha, Birbal Sahni, H. J. Bhabha, S. Chandrasekhar, Shanti Swarup Bhatnagar, S. N. Bose, P. C. Mahalanobis, K. S. Krishnan, S. K. Mitra, D. N. Wadia, T. R. Seshadri, N. R. Dhar, J. C. Ghosh, and several others, whose contributions in the concerned disciplines have been outlined in the articles presented in Part II. This crop of outstanding work by any standard has been possible within such a short time because the country had a long and deep-rooted tradition in science which was never completely dimmed by her political vicissitudes.

This volume is the intellectual product of a large number of scholars who have ungrudgingly responded to our request for contribution to the *Heritage*. Despite the delay in publication and consequent irritation they have all borne with us with exemplary patience. We express to them our grateful thanks for their contributions and co-operation. This volume in its present form would not have been possible but for the care and efforts of Swami Viprananda; Sri A. K. Mukherjee, the Registrar of the Institute; Sri Jyotirmoy Basu Ray; and Sri Krishna Sen Gupta. They went over the articles several times, read the proofs, attended to the critical apparatus such as the footnotes, the bibliography, and the index and other indispensable details of production. We place on record our deep appreciation of their service.

Calcutta

S. N. SEN

INTRODUCTION

1

INTRODUCTION

THE impression that science started only in Europe was deeply embedded in the minds of educated people all over the world until recently. The alchemists of Arab countries were occasionally mentioned, but there was very little reference to India and China. Thanks to the work of the Indian National Science Academy and other learned bodies, the development of science in India during both the ancient and medieval periods has recently been studied. It is becoming clearer from these studies that India has consistently been a scientific country, right from Vedic to modern times with the usual fluctuations that can be expected of any country. In fact, I do not find an example of a civilization, except perhaps that of ancient Greece, which accorded the same exalted place to knowledge and science as did that of India. There is nothing that bears comparison to knowledge (*nahi jñānena sadṛśam*): this epitomized our culture's homage to learning and inspired our ancients' quest for knowledge. The articles written by distinguished scholars for this volume of *The Cultural Heritage of India* published by the Ramakrishna Mission Institute of Culture illustrate this spirit.

It is universally acknowledged that much of mathematical knowledge in the world originated in India and moved from East to West. The high degree of sophistication in the use of mathematical symbols and developments in arithmetic, algebra, trigonometry, and astronomy, especially the work attributed to Āryabhaṭa, is indeed remarkable and should be a source of inspiration to all of us in India. The articles which describe Indian contributions to science from the ancient times to the very modern period bring out quite clearly the continuity of scientific thought as a part of our cultural heritage. It is, however, unfortunate that the period of decline in India coincided with that of ascendency in Europe. It is perhaps the contrast during this period that made Europeans believe that all modern science was European.

Even in the last century new dimensions were added to science and technology in this subcontinent though the scientists were mainly Europeans. This is with special reference to seismology, astronomy, and geology. Since the spirit of science already existed in India it did not take her very long to absorb the great developments in Europe and start making her own contributions. However, technology was at a low ebb since industry was not encouraged during this period. The cream of our intelligentsia was drawn towards subordinate administrative roles with the result that technology which constitutes a vital link between science and development, the *sine qua non* of any break-through in a nation's effort towards modernization, did not grow. Recognition of this

lacuna soon after independence has, however, set things right. The articles on space and atomic energy record India's up-to-date achievements in those fields and show how quickly India has caught up with front-ranking countries in science and technology. Our successes in scientific agriculture are another proof that Indian citizens are willing to accept modern technology wherever it is of value to them.

One can always ask the question as to why with all our background we did not have an industrial revolution earlier. Why is there so much superstition and irrationality and why is creative thinking still not so vibrant as it is in the West? Talking of superstition and irrationality, one can see them everywhere, even in the most advanced countries of the West. As regards creative thinking, India has been a pioneer in art and literature in the past, and there are signs that she has again become active in those fields. Nevertheless, that we have made great progress in many directions can be seen by contrast with the development in neighbouring countries which, in spite of their economic strength, are yet to recapture the spirit of scientific research and self-reliance. But much still remains to be done in India, something in the nature of a cultural renaissance to rekindle that spirit of rational appraisal and response to phenomena, both natural and man-made, among the lay public.

The Ramakrishna Mission Institute of Culture has at a very appropriate time brought out this volume which substantiates much of what I have said above. However, in passing, one would like to ask the question: Are the fluctuations of our contributions to scientific knowledge due to our social structure or due to political subjugation? Somehow one has a feeling that had we not discarded the pragmatic spirit of Buddhism the way we did, the scientific activities of India would not have suffered a decline like they did.

PART I

SCIENCE AND TECHNOLOGY IN ANCIENT AND MEDIEVAL INDIA

2

GEOGRAPHICAL KNOWLEDGE

GEOGRAPHY as a branch of scientific study has developed as a consequence of man's immediate need for functioning in the world around him. Familiarity with the surrounding terrain, its lakes and rivers, the climatic conditions, and the neighbouring tribes—matters of daily experience—was the rudimentary beginning of geographical study.

In India the earliest references to geographical data are found in the *Ṛg-Veda.* Casual references to tribes, rivers, and other geographical landmarks indicate that geographical knowledge was not lacking during the Vedic period. The subject may be studied with reference to the (i) Vedic and (ii) Post-Vedic periods.

VEDIC PERIOD

The ancient Indians' conceptions of the universe and the earth determined to a great extent their understanding of the earth's physical properties and conditions. In Vedic literature the universe is sometimes conceived as consisting of the earth and sky (heaven), and sometimes of the earth, air (atmosphere), and sky.[1] Solar bodies are understood as belonging to the realm of the sky and atmospheric phenomena such as lightning to that of the air. The semi-spherical shape of the sky as seen by the eye led to the comparison in the *Ṛg-Veda* of the sky and earth to two great bowls (*camvā*) turned towards each other (III.55.20). The *Śatapatha Brāhmaṇa* (IV.6.5.1) uses the term *graha,* which later came to mean 'planet', but in this text the word seems to signify a sort of power. The question whether the Vedic Indian used the word to denote 'planet' is not free from doubt. Some scholars like Oldenberg identify the *grahas* with the *ādityas,* numbering seven—the sun, moon, and the five planets.[2] Hillebrandt thinks that the planets are the *adhvaryus* referred to in the *Ṛg-Veda* (III.7.7).[3]

The earth is denoted in the *Ṛg-Veda* by such words as *pṛthivī* (the expansive or large), *pṛthvī* or *urvī* (the broad), *mahī* (the great), *apārā* (the limitless), and *uttānā* (the stretched out). The *Ṛg-Veda* contains references suggesting the spherical shape of the earth. It says, for instance, that every sacrificial altar or ground on the surface of the earth is its centre (III.5.9; IX.86.8).

[1]A. A. Macdonell, *The Vedic Mythology* (Indological Book House, Varanasi, 1963), pp. 8-11.

[2]H. Oldenberg, *Religion des Veda,* pp. 185 *et seq.; Zeitschrift der Deutschen Morgenländischen Gesellschaft,* pp. 50, 56 *et seq.*

[3]A. Hillebrandt, *Vedische Mythologie,* pp. 3 and 423.

This has been interpreted as implying the earth's sphericity. Elsewhere the earth is compared to a wheel (X.89.4) and the dawn is stated to precede the sunrise (I.123.1). In the *Śatapatha Brāhmaṇa* the earth is expressly mentioned as being circular (*parimaṇḍala*).[4] In the cosmogonic and theosophic hymns of the *Atharva-Veda* the earth and the heavens have been imagined as constituting two hemispheres (XI.5.8-11). The Vedic Hindus had clear ideas about the four directions (*diś*), further elaborated in connection with the placement of sacrificial altars (*vedi*, *citi*).

The term *dvīpa* (island) occurs in the *Ṛg-Veda* (I.169.3) and other Vedic texts. But it is unlikely that the word refers to any island, continent, or major land area as it does in the Epics and Purāṇas. Sandbanks are perhaps indicated by the term.[5] It appears likely that no major geographical divisions of the earth are mentioned in Vedic literature. Use of the expression *sapta sindhavaḥ* (VIII.24.27), i.e. 'seven rivers', however, has led some scholars to think that the Ṛg-Vedic Indians conceived of a definite territory covering the basin of some of the existing rivers.[6] The names of a large number of rivers occur in the *Ṛg-Veda* (X.75.5-6). Some among these are the Sindhu, Gaṅgā, Yamunā, Sarasvatī, Śatadru, Vitastā, Sarayu, and Gomatī. The *Ṛg-Veda* also refers to mountains, e.g. the Himavant (X.121.4) and Mūjavant (X.34.1). The Himavant may reasonably be identified with the Himalayas, though it is possible that it included hills of the Suleiman range. The ancient lexicographer Yāska suggests that Mūjavant is equivalent to Muñjavant which figures in the *Mahābhārata* (X.785; XIV.180) as the name of a mountain in the Himalayan range. The *Kauṣītaki Upaniṣad* (II.13) speaks of the Dakṣiṇa-parvata, which is probably to be identified with the Vindhyan range. The names of many places also figure in Vedic texts.

In the Vedic period a kind of zonal geographical conception evolved. The *Śatapatha Brāhmaṇa* (I.7.3.8) calls the people of eastern India the Prācyas and those of western India the Bāhīkas. The expression *madhyamā pratiṣṭhā diś* (the middle fixed region) occurs in the *Aitareya Brāhmaṇa* (VIII.14.3). The inhabitants of this region are stated to be the Kurus, Pañcālas, Vaśas, and Uśīnaras. This middle zone is called Āryāvarta in the *Baudhāyana Dharmasūtra* (I.2.10) and is described as the area north of the Pāriyātra or Pāripātra (western Vindhyas), east of Adarśana (near Kurukṣetra), south of the Himavat (Himālaya), and west of Kālakavana (probably near Allahabad).[7]

POST-VEDIC PERIOD

Abundant evidence of the geographical knowledge of the Indian people is available in post-Vedic literature. The Epics contain numerous incidental geographical references about the earth in general and Bhāratavarṣa in particular, the latter being especially dealt with in the *Kiṣkindhā-kāṇḍa* of the *Rāmāyaṇa* and the *Bhīṣma-parvan* of the *Mahābhārata*. Pāṇini's *Aṣṭādhyāyī* and Patañjali's *Mahābhāṣya* allude to some of the then prevailing conceptions of the earth and provide considerable details relating to the geography of the subcontinent. Buddhist works like the *Vinaya Piṭaka*, *Mahāvastu*, and the Nikāyas, particularly the *Aṅguttara Nikāya*, are important sources of geographical information. Indeed, from about the time of Buddha to that of Aśoka, Buddhist canonical literature constituted the principal source of geographical information about contemporary India. Even for later periods, the works of Buddhaghoṣa and the Ceylonese chronicles *Dīpavaṁsa* and *Mahāvaṁsa* provide valuable references. The Buddhist Jātaka stories mention various places and add to our geographical knowledge of the country. Chinese Buddhist accounts also throw considerable light on the geography of India. Among the accounts left by Chinese travellers, particular importance is given to those of I-tsing, Fa Hien, and Hiuen Tsang. The Jaina canonical texts and Apabhraṁśa literature together with the Prabandhas furnish valuable geographical data and supplement the information given by the Buddhist texts.

The Purāṇas constitute the most detailed and comprehensive source of geographical knowledge of the post-Vedic period. They seem to have originated prior to the fifth or fourth century B.C., but in their present form they cannot be dated earlier than the seventh century A.D. The Purāṇas draw much of their material from the Epics, but they expand the concepts and furnish greater details. According to Ali, the range of their treatment of the subject covers the 'geography of practically the whole of the old world, the surrounding oceans and observation of some of the atmospheric phenomena'.[8] The treatment of geographical information is not uniform in all the Purāṇas: some go into greater detail than others. The *Vāyu*, *Brahmāṇḍa*, *Vāmana*, and *Mārkaṇḍeya*, for instance, contain sections entitled *Bhuvana-koṣa*, *Bhuvana-vinyāsa*, *Jambudvīpa-varṇana*, and so on, which deal primarily with geographical information.

Kauṭilya's *Arthaśāstra* and medical works like the *Caraka* and *Suśruta* provide additional details by way of mentioning the natural products of different regions. The astronomical works of Varāhamihira, Parāśara, and others contribute topographical data regarding the regions of the subcontinent and are valuable sources of the knowledge of mathematical geography which developed

in the post-Vedic period. Literary works of Kālidāsa, Bāṇa, Kalhaṇa, Rājaśekhara, and others also contain geographical references. Epigraphic records are innumerable and replete with geographical material relating to India and her colonies. In addition to the accounts of Chinese travellers, the reports of foreigners like Megasthenes, al-Bīrūnī, and Abū'l-Fazl are important eye-witness records of the regions of the subcontinent.

The Earth and its Dvīpas: The concept of the earth comprising a number of *dvīpas*, meaning continents, seems to have emerged in the post-Vedic period. The *Mahābhārata* gives the number of such continents variously in its different sections. In the *Bhīṣma-parvan* (6.13) four major *dvīpas* are mentioned; elsewhere seven, eleven, and thirteen have been spoken of. The earliest references to the seven-continent theory occur in the *Rāmāyaṇa, Mahābhārata*, and Patañjali's *Mahābhāṣya*. The Pali Buddhist literature mentions four *mahādvīpas* (great islands), namely, Uttara-Kuru or Kuru in the north, Jambudvīpa in the south, Pūrva-Videha in the east, and Apara-Godāna in the west, as constituting the earth. The *Mahābhārata* gives a description of these four regions, Jambudvīpa in particular. Use of the term *cakravāla-rājya* to mean the whole world is also found in Pali literature. The *cakravāla* is conceived as 'a vast circular plane covered with water with Mount Meru or Mahāmeru standing at the centre'.[9] Seven *kulācalas* or concentric circles of rock surround Meru. Beyond these are the four great *dvīpas*, one in each of the cardinal directions. The post-Gupta Jaina work *Tiloyapaṇṇatti* (V.11-26) speaks of the earth being constituted of sixteen inner and sixteen outer islands, each having an ocean beyond it.

According to most Purāṇas, the earth (*pṛthivī*) consists of seven *dvīpas*. These are said to be seven concentric circles of land, like seven rings, one inside the other. The names of the *dvīpas* beginning from the innermost are Jambu, Plakṣa, Śālmali(a), Kuṣa, Krauñca, Śāka, and Puṣkara.[10] Each of these *dvīpas* is said to be surrounded by a particular sea. Beginning from the innermost, these are named Lavaṇa (salt-water), Ikṣu (sugar-cane juice), Surā (wine), Sarpi (ghee), Dadhi (curd), Kṣīra or Dugdha (milk), and Svādūdaka or Jala (fresh-water).[11] The question which arises is: What is really meant by the Purāṇic *dvīpas*[12] and seas? The Purāṇas appear to imply by the term *dvīpa* 'any land which was ordinarily inaccessible or detached by virtue of its being surrounded by water, sand, swamp or even high mountains or thick forests'.[13] Thus the term may indicate an island, a peninsula, or a doab, or even a specific area of land, large or small, which is distinguished by particular geographical

[9]Sircar, *op. cit.*, p. 39.

[10]*Mārkaṇḍeya Purāṇa*, LIV. 6.

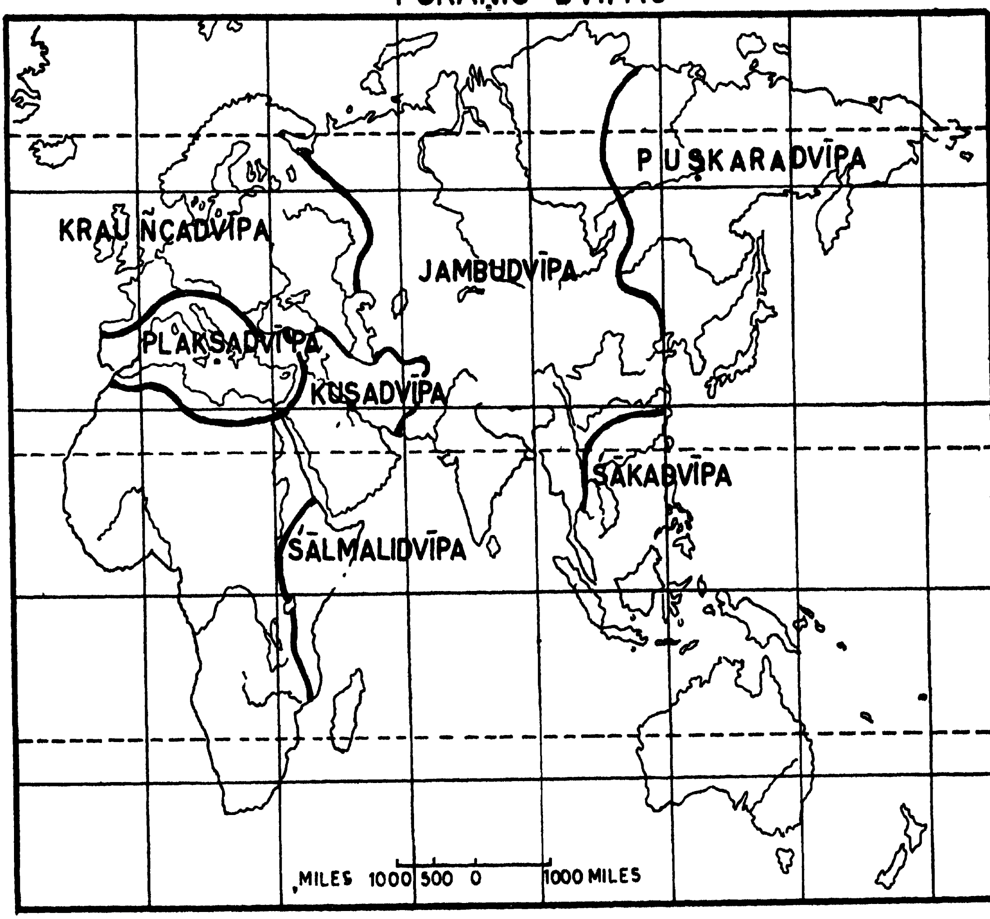
[11]*Ibid.*, LIV. 7.

[12]Pāṇini derives *dvīpa* from *dvi* + *ap*, meaning 'land between two arms of water' (*Aṣṭādhyāyī*, V. 4. 74; VI. 3. 97).

[13]S. M. Ali, *The Geography of the Puranas* (People's Publishing House, New Delhi, 1966), p. 37.

features. It may also stand for tribal or national territories. The Purāṇic *dvīpa* therefore signified 'all types of natural or human regions — big or small'.[14] The descriptions of the seven seas as consisting of sugar-cane juice, wine, etc. should not be taken too literally. They may indicate that these seas had special characteristics which distinguished them from each other. Similar names — the Red Sea, Black Sea, and White Sea, for instance — are found even today, but they

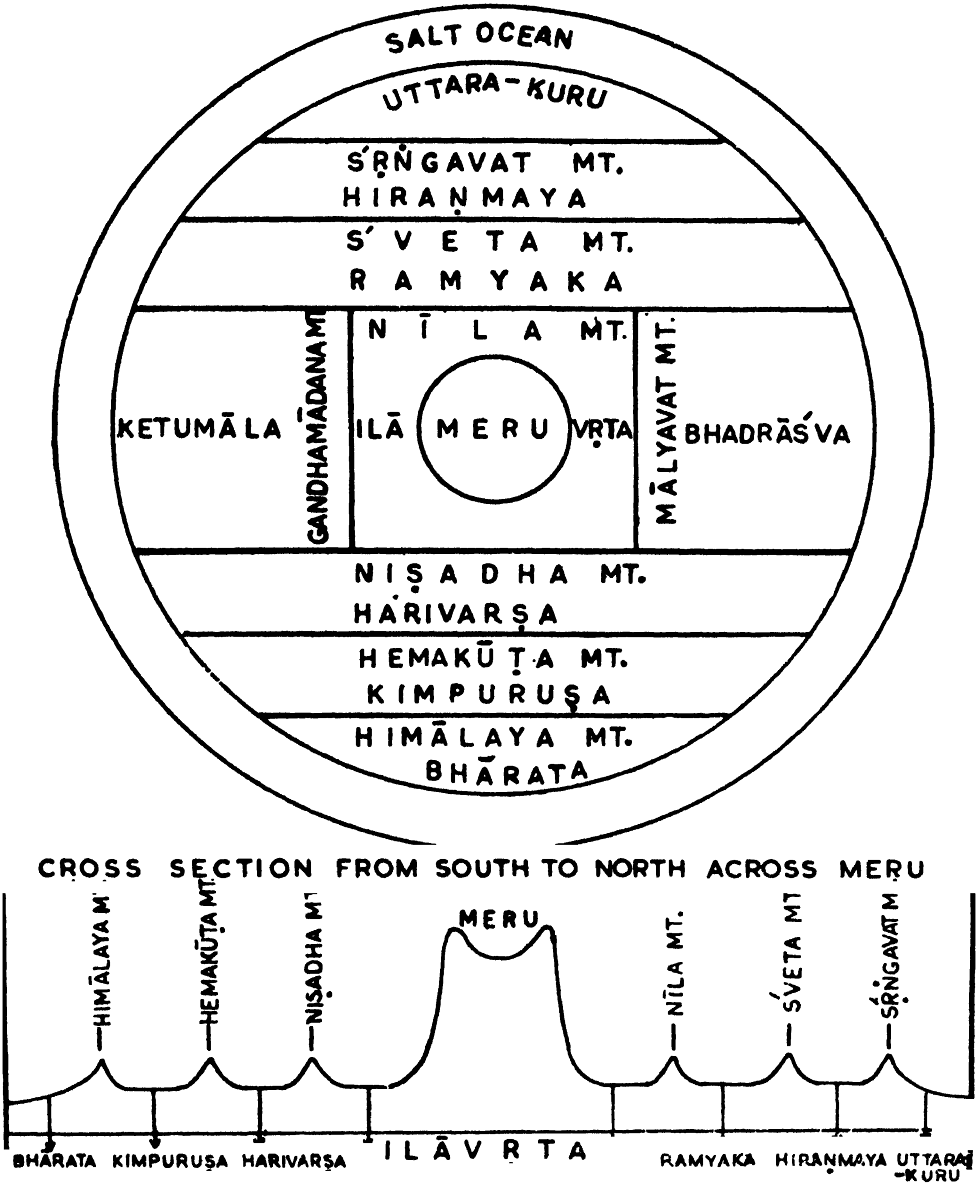
PURĀṆIC DVĪPAS



are not taken in their literal sense. One of the Jātaka stories lends credence to the idea that the seas were named after certain characteristics found to be present in them. The story narrates how a ship which was carried off its course by a storm passed in turn through seas named Aggimāla (blazing like fire), Dadhimāla (the colour of curd), Nīlavaṇṇa-kusamāla (the colour of *Poa cyno-*

[14] *Ibid.*

JAMBUDVĪPA OF THE PURĀṆA



suroides grass), and Nalamāla (red like coral).[15] The Epic and Purāṇic periods are marked by predominance of mythology, albeit not entirely devoid of factual elements. The theory of seven concentric *dvīpas* and seas seems to have developed out of this mythological conception of the world. The Purāṇic writers apparently tried to fit geographical data based on tradition and reports of over-imaginative travellers into a mythological concept.

Most of the Purāṇas give details of the vegetation, rivers, mountains, climates, etc. of the *dvīpas*. Some scholars have, on studying these details, tried to identify specific geographical regions with the *dvīpas* spoken of. Even though one may not fully agree with such specific identification, it cannot be denied that the Purāṇic details of the seven *dvīpas*, whether based on concrete information (the chain of which has been lost in the course of time) or on limited data supplemented by imagination, do fit in with the geographical features of some of the existing land and water masses on the earth's surface. Reference may be made in this connection to al-Bīrūnī's (*c.* eleventh century) locating the Puṣkaradvīpa between Cīna and Maṅgala (perhaps China and Mongolia).

The Purāṇas contain an elaborate list of mountains and mountain ranges of the seven *dvīpas*. The most commonly mentioned mountain is Meru which is at the centre of the seven *dvīpas*, that is, in the centre of Jambudvīpa. Similar descriptions of the river systems of the seven *dvīpas* occur in the Purāṇas, signifying familiarity of the contemporary people with the geographical features of not only the regions of their natural habitat but also the old world as a whole.

Jambudvīpa: Geographical knowledge becomes more intimate as one turns to Jambudvīpa. The *Mahābhārata* provides a detailed description of Jambudvīpa, also called Sudarśanadvīpa. It is spoken of as circular in shape (VI.5.12). Surrounded on all sides by the sea, it has six mountain ranges running east-west: Himālaya, Hemakūṭa, Niṣadha, Nīla, Śveta, and Śṛṅgavat (VI.6.4-5). Jambudvīpa is divided into nine zones (*varṣas*): Hari, Bhadrāśva, Ketumāla, Bhārata, Uttara-Kuru, Śveta, Hiraṇyaka, Airāvata, and Ilāvṛta (VI.6.8,13,37-38). According to Jaina writers, Jambudvīpa has seven *varṣas* created by six mountain ranges called *varṣa-parvatas* running from east to west.

The *Mārkaṇḍeya Purāṇa* (LIV. 12ff.) describes Jambudvīpa as depressed on the south and north and elevated and broad in the middle. This elevated region is Ilāvṛta (also called Meruvarṣa), at the centre of which is the mountain Meru. In different Purāṇic texts Jambudvīpa is said to be composed of the following nine divisions: (i) Ilāvṛta, (ii) Ramyaka or Ramaṇaka, (iii) Hiraṇmaya or Hiraṇyaka, (iv) Uttara-Kuru or Śṛṅgaśaka, (v) Bhadrāśva, (vi) Ketumāla, (vii) Hari, (viii) Kimpuruṣa, and (ix) Bhārata.[16] Relative to the central

[15] *The Jataka*, ed. E. B. Cowell, Vol. IV (Luzac and Co. for Pali Text Society, London, 1957), Bk. XI, pp. 88-89.

[16] *Matsya Purāṇa*, CXIII. 26-31. Another tradition current in the *Markaṇḍeya* (LV. 20ff.) and *Brahmāṇḍa* (XXXV. 50) *Purāṇas* divides Jambudvīpa into four regions shaped like four petals of a lotus.

varṣa Ilāvṛta, the next three figure in the north, the last three in the south, while Bhadrāśva and Ketumāla are to the east and west respectively. Four rivers are stated to flow from Meru —Bhadrā to the north, Sītā to the east, Gaṅgā to the south, and Cakṣu to the west. There are three mountain ranges north of Ilāvṛta —Nīla, Śveta, and Śṛṅgavat —each consecutive range occurring after each successive *varṣa*. Similarly, three ranges stand south of Ilāvṛta: Niṣadha, Hemakūṭa, and Himālaya. To the east and west of Ilāvṛta running north-south are the Mālyavat and Gandhamādana ranges respectively. The descriptions of the three *varṣas* to the north of Meru, some of which are also mentioned in the *Mahābhārata* (*Bhīṣma-parvan*), are rather sketchy in the Purāṇas. Nevertheless, the details of the three latitudinal ranges —Nīla, Śveta, and Śṛṅgavat— of this region, their valleys, river systems, and other information as available in the *Vāyu Purāṇa*, make it possible to identify quite a few of their important geographical features. According to Ali, the description of the northern regions of Jambudvīpa 'covers a very vast area, from the Urals and the Caspian to the Yenisei and from the Turkestan, Tien-Shan ranges to the Arctic. It describes the topography of the whole land very accurately and in some cases picturesquely. . . .'[17] Turning east, Bhadrāśva is 'identical with the basins of the Tarim and Hwangho rivers, i.e., the whole of Sinkiang and Northern China'.[18] Ketumāla, located to the west of Meru, is irrigated by the river Cakṣu, which is probably the Oxus. This region corresponds to western Turkestan.[19] Ketumāla is believed to cover 'practically the whole of the ancient Bactria which included the whole of the present Afghan Turkistan (north of Hindukush), the lower Hari Rud Valley, the basin of Murghab Kashka system (all south of the old bed of Āmū Darya) and the basins of the Surkhan, Kafirnigan, Vakhsh and Yaksu rivers . . . .'[20] Hari appears to have been western Tibet;[21] Kimpuruṣa was presumably Nepal;[22] and Bhārata probably means greater India.

Bhāratavarṣa: The concept of Bhāratavarṣa as we know it did not emerge apparently before the fourth century B.C., for Pāṇini's *Aṣṭādhyāyī* (*c.* fifth century B.C.) makes no mention of the southern and extreme eastern regions of the subcontinent.[23] In the third century B.C., however, references to the South Indian peoples like the Colas and Pāṇḍyas occur in Kātyāyana's *vārttikas* and in the accounts of Megasthenes. This indicates a growing awareness of the extent of the subcontinent and of the peoples who inhabited it.

[17] Ali, *op. cit.*, p. 87.

[18] *Ibid.*, p. 99; H. Raychaudhuri, *Studies in Indian Antiquities* (University of Calcutta, 1932), pp. 75-76.

[19] Raychaudhuri, *op. cit.*, p. 75.

[20] Ali, *op. cit.*, p. 97.

[21] N. L. Dey, *The Geographical Dictionary of Ancient and Mediaeval India* (Luzac and Co., London, 1927), p. 74.

[22] *Ibid.*, p. 100.

[23] Sircar, *op. cit.*, pp. 34ff.

The Buddhist and Jaina canonical works of the fourth-second centuries B.C. mention sixteen *mahājanapadas* (great states) comprising much of the area of the subcontinent. The nomenclature of the *mahājanapadas* differs in the two traditions. The regions noted in each are mostly confined to the northern and western parts of the subcontinent with occasional reference to the east and south. Aśoka's (269-232 B.C.) empire comprised almost the whole of the Indian subcontinent and parts of Afghanistan. This area, which practically corresponds to what subsequently came to be known as Bhāratavarṣa, is referred to in his inscriptions as *pṛthivī* and *jambudvīpa*. The earliest epigraphic reference to the name 'Bhāratavarṣa' is found in the Hāthigumphā inscription of Khāravela (first century B.C.).[24]

The term 'Bhāratavarṣa' occurring in the *Mahābhārata* (VI.9.10ff.) stands for a vast area comprising numerous rivers, mountains, and territories which are described in some detail. It is not possible, however, to construct a precise geographical outline of this area because the boundaries are not clearly defined. Seven major mountains and ranges are named (VI.9.11): (i) Mahendra (Eastern Ghats), (ii) Malaya (Travancore Hills and the southernmost portion of the Western Ghats), (iii) Sahya (Western Ghats to the north of Malaya), (iv) Śuktimat (parts of the Vindhyan range including the Sakti Hills in eastern M.P.), (v) Ṛkṣavat (parts of the Vindhyan range to the south of Malwa), (vi) Vindhya (the Vindhyan range from Gujarat to Bihar excluding portions covered by Śuktimat, Ṛkṣavat, and Pāripātra), and (vii) Pāripātra or Pāriyātra (the Western Vindhyan range including the Aravallis).[25] Among the important rivers mentioned are the Gaṅgā, Sindhu, Sarasvatī, Godāvarī, Narmadā, Śatadru, Candrabhāgā, Irāvatī, Vipāśā, and Yamunā. A list of more than seventy major territorial units (*janapadas*) other than those in the south is given. Among these are Sindhu, Videha, Magadha, Aṅga, Vaṅga, Kaliṅga, Gāndhāra, and Kāśmīra. The southern part of Bhāratavarṣa is said to include territories like Draviḍa, Kerala, Mālava, Karṇāṭaka, and Cola.

Some geographical information about Bhāratavarṣa, particularly the south, also occurs in the *Rāmāyaṇa*. Rāma's journey from Ayodhyā to Kanyākumārī, the gateway to Laṅkā (Ceylon), provides the context for describing the forests, rivers, and *janapadas* on the way (IV.42-43).

Bhārata or Bhāratavarṣa is described in the Purāṇas as semi-circular[26] and lying between the Himavat in the north and the sea in the south.[27] The *Mārkaṇḍeya Purāṇa* (LVII.58-59) depicts this region as having the Himavat like the string of a bow in the north and the sea in the south, east, and west. The same

[24] *Ibid.*, p. 34.

[25] *Ibid.*, p. 70; Ali, *op. cit.*, pp. 111-13.

[26] *Matsya Purāṇa*, CXIII. 13; *Brahmāṇḍa Purāṇa*, XXXV. 13.

[27] *Uttaraṁ yat samudrasya himavaddakṣiṇañca yat; Varṣaṁ yadbhāratarṁ nāma yatreyaṁ bhāratī prajā. Vāyu Purāṇa*, XLV. 75-76.

text gives its shape as conforming to that of a tortoise lying outspread and facing eastward (LVIII.4), and also refers to Bhārata as being constituted with a fourfold conformation (LVII.58-59).

Bhāratavarṣa has been spoken of in ancient texts variously as comprising five, seven, and nine divisions. The *Mahābhārata*, a few of the Purāṇas,[28] Buddhist writers like Hiuen Tsang (seventh century), and Rājaśekhara (*c*. 900) in his *Kāvyamīmāṁsā* speak of five regions. These are named (i) Madhyadeśa (central), (ii) Udīcya (northern), (iii) Prācya (eastern), (iv) Dakṣiṇāpatha (southern), and (v) Aparānta (western). Madhyadeśa has been defined as the land bounded by the Himalayas in the north, the Vindhyas in the south, Vinaśana (in Ambala district) in the west, and Prayāga (Allahabad) in the east.[29] Udīcya covers eastern Punjab and the Oxus valley including the Himalayas. Its southern boundary may be taken as the river Sutlej. Prācya extends from the eastern end of Madhyadeśa to the Assam hills and from the Himalayas to the eastern coastal plain. This region may have included Kāśī, Kośala, Videha, and Magadha. Dakṣiṇāpatha includes the entire area of South India to the south of the Vindhyas. Aparānta is the area lying to the west of Madhyadeśa and seems to have comprised Sind, western Rajasthan, Gujarat, and a part of the adjoining coast on the lower course of the Narmadā.

Reference to a division into seven zones is also found in the *Mahābhārata* and most of the Purāṇas. This classification is not essentially different from that consisting of five regions. In addition to the five already mentioned, the Himalayan region and the Vindhyan range are included as the sixth and seventh divisions.

A third classification which divides Bhāratavarṣa into nine regions, current in several of the Purāṇas and the *Kāvyamīmāṁsā*, has probably been borrowed from the astronomical works of Parāśara and Varāhamihira, although likely to be of earlier origin.[30] The *Mārkaṇḍeya Purāṇa* (LVII.6-7) specifies eight of these regions or *khaṇḍas* as Indradvīpa, Kaśerumat, Tāmravarṇa, Gabhastimat, Nāgadvīpa, Saumya, Gāndharva, and Vāruṇa.[31] Regarding the ninth *khaṇḍa* it simply says: 'It is this one which is girdled by the sea (*sāgarasaṁvṛta*).' The *Kāvyamīmāṁsā* names this ninth *khaṇḍa* as Kumārī; the *Vāmana Purāṇa* calls it Kumāra; and the *Skanda Purāṇa* designates it as Kumārikā.

Opinions differ about the identification of these nine divisions. Abū'l-Fazl and al-Bīrūnī have identified the nine regions within the area of the subcontinent

[28] *Matsya*, *Vāyu*, and *Viṣṇu*.

[29] *Manu-smṛti*, II. 21.

[30] *Cunningham's Ancient Geography of India*, ed. S. Majumdar Sastri (Chuckervertty, Chatterjee & Co., Calcutta, 1924), p. 6.

[31] The *Kūrma Purāṇa* substitutes Tāmraparṇa for Tāmravarṇa, while the *Matsya* calls it Tāmraparṇī. The *Vāmana* and *Garuḍa Purāṇas* have Kaṭāha and Siṁhala in place of Saumya and Gāndharva respectively.

itself.[32] Abū'l-Fazl names seven mountain ranges running east to west between Laṅkā and Himācala: Mahendra, Śukti, Malaya, Rikṣa, Pāriyātra, Sahya, and Vindhya. The region between Laṅkā and Mahendra he calls Indradvīpa; between Mahendra and Śukti, Kaśerumat; between Śukti and Malaya, Tāmravarṇa; between Malaya and Rikṣa, Gabhastimat; between Rikṣa and Pāriyātra, Nāgadvīpa; and between Pāriyātra and Sahya, Saumya. He divides the area between Sahya and Vindhya into two parts, Kumāradvīpa being the eastern section and Vāruṇadvīpa the western.[33] Al-Bīrūnī describes Indradvīpa as central India; Kaśerumat as eastern-central; Tāmravarṇa as south-eastern; Gabhastimat as southern; and Gāndharva as north-western. Ali also locates the nine *khaṇḍas* within the area of the subcontinent. Basing his view on relevant passages of the *Vāyu Purāṇa*, he maintains that Indradvīpa is a region east of the Brahmaputra; Kaśerumat is the eastern coastal plain; Tāmravarṇa is the peninsula south of Kāverī; Gabhastimat is the hilly region between the Narmadā and the Godāvarī; Nāgadvīpa is possibly the area of the Vindhyan and Satpura ranges; Saumya is the coastal belt west of the Indus; Gāndharva is the trans-Indus region; and Vāruṇa is the western coast. He does not offer any identification of the ninth *khaṇḍa*, unnamed in the *Vāyu Purāṇa*.[34]

Majumdar Sastri, on the other hand, considers that the Purāṇic conception of Bhāratavarṣa implies greater India, i.e. India proper plus eight *khaṇḍas* outside the area of the subcontinent. He identifies Indradvīpa with Burma; Kaśerumat with the Malay Peninsula; Tāmravarṇa (Tāmraparṇa) with Ceylon; Gabhastimat with Laccadive, Maldive, or Ernaculam in the south-west; Nāgadvīpa with Salsette, Elephanta, and Kathiawar in the west; and Saumya with Kutch in the north-west. Other identifications include Gāndharva with the Kabul valley; Vāruṇa with the Indian colony in Central Asia; and the ninth division called Kumārī with practically the whole of the Indian subcontinent.[35] Support is lent to this view by the *Kāvyamīmāṁsā* which, in course of describing the mountain ranges of the subcontinent, specifically states: 'This is Kumārīdvīpa.'[36] Similarly, the *Vāmana Purāṇa* (XIII.59), after enumerating the peoples of the respective divisions of India proper, concludes by saying that the detailed narration of the countries of Kumāradvīpa is now complete. Further, the list of the *Varāha Purāṇa* replaces the ninth *dvīpa* Kumāra with the word 'Bhārata', suggesting the identity of the two. It seems likely, therefore, that the term 'Bhāratavarṣa' had both a wider and a narrower connotation and that in the narrower sense it meant India proper. It is well substantiated that

[32] Sircar, *op. cit.*, p. 55.

[33] *'Ain-i-Akbari of Abul Fazl-i-'Allami*, trans. H. S. Jarrett, revised and annotated by Jadu Nath Sarkar, Vol. III (Royal Asiatic Society of Bengal, Calcutta, 1948), pp. 36-37.

[34] Ali, *op. cit.*, pp. 128-30.

[35] *Cunningham's Ancient Geography of India*, ed. S. Majumdar Sastri, Appendix I, pp. 751-54.

[36] *Atra ca kumārīdvīpa.*

Indian colonies were established in the Far East before the Christian era. 'For nearly fifteen hundred years, and down to a period when the Hindus had lost their independence in their own home, Hindu kings were ruling over Indo-China and the numerous islands of the Indian Archipelago, from Sumatra to New Guinea.'[37] Reference may be made in this connection to four inscriptions of King Mūlavarman (*c.* fourth or fifth century A.D.) found in East Borneo, showing that the area was under Indian rule. It is not unreasonable to suppose that these territories were considered a part of greater India and that they might have been included as divisions of Bhāratavarṣa in the Purāṇic scheme.

The Indian subcontinent has been from the dim past the home of many races and peoples. Throughout the ancient period this movement of peoples presented a changing panorama. The impact of these tribes and ethnic groups on the soil of India and their efforts to adjust themselves to the opportunities which the geographical environment afforded provides the background of ancient Indian geography. This is perhaps why the Purāṇas and the astronomical works emphasize the regional conception of geography and take particular note of the *janapadas* and major geographical landmarks. The Purāṇas follow the tradition dating back to the Vedas of using tribal names to indicate the region which particular tribes inhabited. It is clear that such names are ethnographical in character although territorial or place names are by no means few. In fact, the people of Bhāratavarṣa appear in the Purāṇic texts only in their relevant geographical setting, which indicates that in ancient India the different human groups were regarded as so many essential units of a comprehensive geographical system. The lists of *janapadas* occurring in the various Purāṇas are arranged in an almost identical manner, but there are indications that the lists were altered to receive later additions and were brought up to date from time to time by the inclusion of the names of foreign invaders. Thus there is mention of the Yavanas, Śakas, and Pahlavas of the second and first centuries B.C., as well as of the Hūṇas of the fifth century A.D. and the Turuṣkas of the Muslim period. The lists received further alteration with the introduction of the names of *janapadas* and geographical landmarks of newly-explored regions or areas of colonization.

Considerable geographical information about Bhāratavarṣa and its neighbourhood is contained in some texts of medieval Indian literature. Rājaśekhara's *Kāvyamīmāṁsā,* as we have seen, supports the view that the Indian subcontinent (designated Kumārīdvīpa) was one of the units of Bhāratavarṣa. Rājaśekhara devotes one chapter of this work to a detailed description of the major mountains and rivers, and various regions of Bhāratavarṣa. Kalhaṇa's *Rājataraṅgiṇī* (twelfth century) provides excellent topogra-

[37]R. C. Majumdar, H. Raychaudhuri, and K. Datta, *An Advanced History of India* (Macmillan & Co., London, 1960), p. 222.

phical data about the Kāśmīra region of Uttarāpatha (Udīcya). A few lexicons of the period between the eleventh and sixteenth centuries also give some geographical information. Mention may be made in this connection of the following works: Yādavaprakāśa's *Vaijayantī* (eleventh century), Hemacandra's *Abhidhāna-cintāmaṇi* (twelfth century), Puruṣottama's *Trikāṇḍaśeṣa* (twelfth century), and Keśava's *Kalpadruma* (sixteenth century).

3

VEDIC MATHEMATICS

VEDIC Hindus evinced special interest in two particular branches of mathematics, viz. geometry (*śulva*) and astronomy (*jyotiṣa*). Sacrifice (*yajña*) was their prime religious avocation. Each sacrifice had to be performed on an altar of prescribed size and shape. They were very strict regarding this and thought that even a slight irregularity in the form and size of the altar would nullify the object of the whole ritual and might even lead to an adverse effect. So the greatest care was taken to have the right shape and size of the sacrificial altar. Thus originated problems of geometry and consequently the science of geometry. The study of astronomy began and developed chiefly out of the necessity for fixing the proper time for the sacrifice. This origin of the sciences as an aid to religion is not at all unnatural, for it is generally found that the interest of a people in a particular branch of knowledge, in all climes and times, has been aroused and guided by specific reasons. In the case of the Vedic Hindu that specific reason was religious. In the course of time, however, those sciences outgrew their original purposes and came to be cultivated for their own sake.

The *Chāndogya Upaniṣad* (VII.1.2, 4) mentions among other sciences the science of numbers (*rāśi*). In the *Muṇḍaka Upaniṣad* (I.2. 4-5) knowledge is classified as superior (*parā*) and inferior (*aparā*). In the second category is included the study of astronomy (*jyotiṣa*). In the *Mahābhārata* (XII.201) we come across a reference to the science of stellar motion (*nakṣatragati*). The term *gaṇita*, meaning the science of calculation, also occurs copiously in Vedic literature. The *Vedāṅga Jyotiṣa* gives it the highest place of honour amongst all the sciences which form the Vedāṅga. Thus it was said: 'As are the crests on the heads of peacocks, as are the gems on the hoods of snakes, so is the *gaṇita* at the top of the sciences known as the Vedāṅga.'[1] At that remote period *gaṇita* included astronomy, arithmetic, and algebra, but not geometry. Geometry then belonged to a different group of sciences known as *kalpa*.[2]

Available sources of Vedic mathematics are very poor. Almost all the works on the subject have perished. At present we find only a very short treatise on Vedic astronomy in three recensions, namely, the *Ārca Jyotiṣa*, *Yājuṣa Jyotiṣa*, and *Atharva Jyotiṣa*. There are six small treatises on Vedic geometry belonging

[1] *Yathā śikhā mayūrāṇāṁ nāgānāṁ maṇayo yathā; Tadvedāṅgaśāstrāṇāṁ gaṇitaṁ mūrdhani sthitam. Vedāṅga Jyotiṣa* (Yajurvedic recension), verse 4.

[2] B. Datta, 'The Scope and Development of the Hindu Gaṇita', *The Indian Historical Quarterly*, Vol. V (Calcutta, 1929), pp. 479-512.

to the six schools of the Veda. Thus, for an insight into Vedic mathematics we have now to depend more on secondary sources such as the literary works.

ASTRONOMY

There is considerable material on astronomy in the Vedic Saṁhitās. But everything is shrouded in such mystic expressions and allegorical legends that it has now become extremely difficult to discern their proper significance. Hence it is not strange that modern scholars differ widely in evaluating the astronomical achievements of the early Vedic Hindus. Much progress seems, however, to have been made in the Brāhmaṇa period when astronomy came to be regarded as a separate science called *nakṣatra-vidyā* (the science of stars). An astronomer was called a *nakṣatra-darśa* (star-observer) or *gaṇaka* (calculator).

According to the *Ṛg-Veda* (I.115.1, II.40.4, etc.), the universe comprises *pṛthivī* (earth), *antarīkṣa* (sky, literally meaning 'the region below the stars'), and *div* or *dyaus* (heaven). The distance of the heaven from the earth has been stated differently in various works. The *Ṛg-Veda* (I.52.11) gives it as ten times the extent of the earth, the *Atharva-Veda* (X.8.18) as a thousand days' journey for the sun-bird, the *Aitareya Brāhmaṇa* (II.17.8) as a thousand days' journey for a horse, and the *Pañcaviṁśa Brāhmaṇa* (XVI.8.6) as the distance equivalent to a thousand cows, one standing on the other, and again (XXI.1.9) as a thousand leagues, besides the two preceding estimates. All these are evidently figurative expressions indicating that the extent of the universe is infinite.

There is speculation in the *Ṛg-Veda* (V.85.5, VIII.42.1) about the extent of the earth. It appears from passages therein that the earth was considered to be spherical in shape (I.33.8) and suspended freely in the air (IV.53.3). The *Śatapatha Brāhmaṇa* describes it expressly as *parimaṇḍala* (globe or sphere). There is evidence in the *Ṛg-Veda* of the knowledge of the axial rotation and annual revolution of the earth.[3] It was known that these motions are caused by the sun.

According to the *Ṛg-Veda* (VI.58.1), there is only one sun, which is the maker of the day and night, twilight, month, and year. It is the cause of the seasons (I.95.3). It has seven rays (I.105.9, I.152.2, etc.), which are clearly the seven colours of the sun's rays. The sun is the cause of winds, says the *Aitareya Brāhmaṇa* (II.7). It states (III.44) further: 'The sun never sets or rises. When people think the sun is setting, it is not so; for it only changes about after reaching the end of the day, making night below and day to what is on the other side. Then when people think he rises in the morning, he only shifts himself about after reaching the end of the night, and makes day below and

[3]See Tarakeswar Bhattacharya's article in *Bhāratavarṣa*, Vol. VII, Pt. I (1326 B.S.), pp. 729ff.; and Ekendranath Ghosh's 'Studies on Rig-Vedic Deities—Astronomical and Meteorological', *Journal of the Asiatic Society of Bengal*, Vol. XXVIII (1932), p. 11.

night to what is on the other side. In fact he never does set at all.' This theory occurs probably in the *Ṛg-Veda* (I.115.5) also. The sun holds the earth and other heavenly bodies in their respective places by its mysterious power.

In the *Ṛg-Veda*, Varuṇa is stated to have constructed a broad path for the sun (I.28.8) called the path of the *ṛta* (I.41.4). This evidently refers to the zodiacal belt. Ludwig thinks that the *Ṛg-Veda* mentions the inclinations of the ecliptic with the equator (I.110.2) and the axis of the earth (X.86.4).[4] The apparent annual course of the sun is divided into two halves, the *uttarāyaṇa* when the sun goes northwards and the *dakṣiṇāyana* when it goes southwards. Tilak has shown that according to the *Śatapatha Brāhmaṇa* (II.1.3.1-3) the *uttarāyaṇa* begins from the vernal equinox.[5] But it is clear from the *Kauṣītaki Brāhmaṇa* (XIX.3) that those periods begin respectively from the winter and summer solstices. The ecliptic is divided into twelve parts or signs of the zodiac corresponding to the twelve months of the year, the sun moving through the consecutive signs during the successive months. The sun is called by different names at the various parts of the zodiac, and thus has originated the doctrine of twelve *ādityas* or suns.

The *Ṛg-Veda* (IX.71.9 etc.) says that the moon shines by the borrowed light of the sun. The phases of the moon and their relation to the sun were fully understood. Five planets seem to have been known. The planets Śukra or Vena (Venus) and Manthin are mentioned by name.

The *Ṛg-Veda* mentions thirty-four ribs of the horse (I.162.18) and thirty-four lights (X.55.3). Ludwig and Zimmer think that these refer to the sun, the moon, five planets, and twenty-seven *nakṣatras* (stars).[6] Macdonell and Keith do not support this view, however.[7] The *Taittirīya Saṁhitā* (IV.4.10.1-3) and other works expressly mention twenty-seven *nakṣatras*. The Vedic Hindus observed mostly those stars which lie near about the ecliptic and consequently identified very few stars lying outside that belt. The relation between the moon and *nakṣatras* was conceived as being a marriage union. The *Taittirīya Saṁhitā* (II.3.5.1-3) and *Kāṭhaka Saṁhitā* (XI.3) state that the moon is wedded to the *nakṣatras*. Later on when Abhijit became the pole-star, it was counted as the twenty-eighth *nakṣatra*. In the course of time Abhijit ceased to be the pole-star and the number again came to twenty-seven. The ecliptic was divided into twenty-seven or twenty-eight parts corresponding to the *nakṣatras*, each of which the moon traverses daily during its monthly course.

It appears from a passage in the *Taittirīya Brāhmaṇa* (I.5.2.1) that Vedic astronomers ascertained the motion of the sun by observing with the naked

[4] A. A. Macdonell and A. B. Keith, *Vedic Index of Names and Subjects*, Vol. II (London, 1912), p. 468.
[5] B. G. Tilak, *The Orion or Researches into the Antiquity of the Vedas* (Poona, 1972), pp. 22-26.
[6] Macdonell and Keith, *op. cit.*, Vol. I, p. 410.
[7] *Ibid.*

eye the nearest visible stars rising and setting with the sun from day to day. This passage is considered very important 'as it describes the method of making celestial observations in old times'.[8] Observations of several solar eclipses are mentioned in the *Ṛg-Veda*, a passage of which states that Atri observed a total eclipse of the sun caused by its being covered by Svarbhānu, the darkening demon (V.40.5-9). Atri could calculate the occurrence, duration, beginning, and end of the eclipse. His descendants also were particularly conversant with the calculation of eclipses.[9] In the *Atharva-Veda* (XIX.9.10) the eclipse of the sun is stated to be caused by Rāhu the demon. At the time of the *Ṛg-Veda* the cause of the solar eclipse was understood as the occultation of the sun by the moon. There is also mention of lunar eclipses.

In the Vedic Saṁhitās the seasons in a year are generally stated to be five in number, namely, Vasanta (spring), Grīṣma (summer), Varṣā (rains), Śarat (autumn), and Hemanta-Śiśira (winter). Sometimes Hemanta and Śiśira are counted separately, so that the number of seasons in a year becomes six. Occasional mention of a seventh season occurs, most probably the intercalary month.[10] It is called 'single born', while the others, each comprising two months, are termed 'twins'. Vedic Hindus counted the beginning of a season on the sun's entering a particular asterism. After a long interval of time it was observed that the same season began with the sun entering a different asterism. Thus they discovered the falling back of the seasons with the position of the sun among the asterisms. Vasanta used to be considered the first of the seasons as well as the beginning of the year.[11] The *Taittirīya Saṁhitā* (VI.1.5.1) and *Aitareya Brāhmaṇa* (I.7) speak of Aditi, the presiding deity of the Punarvasu *nakṣatra*, receiving the boon that all sacrifices would begin and end with her. This clearly refers to the position of the vernal equinox in the asterism Punarvasu. There is also evidence to show that the vernal equinox was once in the asterism Mṛgaśirā from whence, in course of time, it receded to Kṛttikā. Thus there is clear evidence in the Saṁhitās and Brāhmaṇas of the knowledge of the precession of the equinox. Some scholars maintain that Vedic Hindus also knew of the equation of time.[12]

GEOMETRY

Śulva (geometry) was used in Vedic times to solve propositions about the construction of various rectilinear figures; combination, transformation, and

[8] Tilak, *op. cit.*, p. 34n.

[9] *Atharva-Veda*, XIII. 2. 4, 12.36; *Śatapatha Brāhmaṇa*, IV. 4. 21.

[10] *Ṛg-Veda*, I. 164. 1; *Atharva-Veda*, VI. 61.2; see also Macdonell and Keith, *op. cit.*, p. 111.

[11] *Taittirīya Brāhmaṇa*, I.1.2.6-7; III. 10. 4. 1.

[12] Dhirendranath Mookerjee, 'Notes on Indian Astronomy', *Journal of the Department of Letters*, Vol. V (Calcutta University, 1921), pp. 277-302; Ekendranath Ghosh, 'Was the Equation of Time Known to the Vedic Sages?', *Indian Historical Quarterly*, Vol. V (1929), pp. 136-37.

application of areas; mensuration of areas and volumes; squaring of the circle and *vice versa;* etc.[13] One theorem which was of great importance to them on account of its various applications is the theorem of the square of the diagonal. It has been enunciated by Baudhāyana (*c.* 600 B.C.) in his *Śulvasūtra* (I.48) thus: 'The diagonal of a rectangle produces both (areas) which its length and breadth produce separately.' That is, the square described on the diagonal of a rectangle has an area equal to the sum of the areas of the squares described on its two sides. This theorem has been given in almost identical terms in other Vedic texts like the *Āpastamba Śulvasūtra* (I.4) and *Kātyāyana Śulvasūtra* (II.11). The corresponding theorem for the square has been given by Baudhāyana (I.45) separately, though it is in fact a particular case of the former: 'The diagonal of a square produces an area twice as much.'[14] That is to say, the area of the square described on the diagonal of a square is double its area.

The converse theorem—if a triangle is such that the square on one side of it is equal to the sum of the squares on the two other sides, then the angle contained by these two sides is a right angle—is not found to have been expressly defined by any *śulvakāra* (geometrician). But its truth has been tacitly assumed by all of them, as it has been freely employed for the construction of a right angle.

The theorem of the square of the diagonal is now generally credited to Pythagoras (*c.* 540 B.C.), though some doubt exists in the matter. Heath asserts, for instance: 'No really trustworthy evidence exists that it was actually discovered by him.'[15] The tradition which attributes the theorem to Pythagoras began five centuries after his demise and was based upon a vague statement which did not specify this or any other great geometrical discovery as due to him. On the other hand, Baudhāyana, in whose *Śulvasūtra* we find the general enunciation of the theorem, seems to have been anterior to Pythagoras. Instances of application of the theorem occur in the *Baudhāyana Śrautasūtra* (X.19, XIX.1, XXVI) and the *Śatapatha Brāhmaṇa* (X.2.3.7-14). There are reasons to believe it to be as old as the *Taittirīya* and other *Saṁhitās*.[16] With Bürk, Hankel, and Schopenhauer, we are definitely of the opinion that the early Hindus knew a geometrical proof of the theorem of the square of the diagonal. It is very probable, and also natural, that the truth of the theorem was first perceived and proved in the case of rational rectangles and then generalized and found to be universally true. On actually drawing the squares

[13]More information on early Hindu geometry will be found in the author's book, *The Science of the Śulva—A Study in Early Hindu Geometry* (Calcutta, 1932). This book will henceforth be referred to as Datta, *Śulva*.

[14]See also *Āpastamba Śulvasūtra*, I.5 and *Kātyāyana Śulvasūtra*, II.12.

[15]T. Heath, *History of Greek Mathematics*, Vol. I (Cambridge, 1921), pp. 144ff.

[16]Datta, *Śulva*, pp. 120ff.

on the sides and diagonal of such a rectangle and dividing them into elementary squares, it will be easily found by calculation that the square on the diagonal is equal to the sum of the squares on the sides (Fig. 3.1).

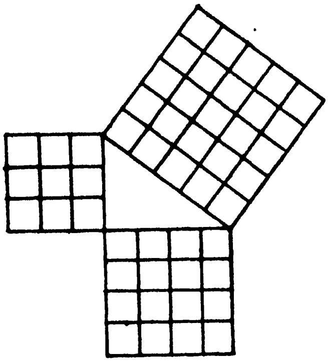


Fig. 3.1

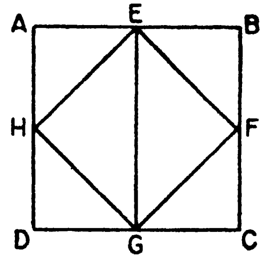


Fig. 3.2

As regards the geometrical evidence, it is natural to presume that the proof of the simpler theorem of the square of the diagonal of a square was discovered first. It seems to have been discovered in the figure of the *paitṛkī-vedi* (Fig. 3.2).

Here the required square figure *EFGH* is obtained by joining the middle points of the sides of a square *ABCD* drawn previously. The square *ABCD* is known to be twice the square *EFGH* in area. It was the usual practice of the Vedic geometers in constructing a square (or indeed any other regular figure of given sides) to do it in such a way as to make it lie symmetrically on the east-west line *EG*. This *EG* is, again, the diagonal of the newly formed square *EFGH*. Thus the square *ABCD* on the diagonal *EG* of the square *EFGH* is twice the square *EFGH*. So this figure leads in a very simple and vivid way to the discovery and proof of the theorem of the square of the diagonal of a square.

How the early Hindus proceeded next to find a general proof is hinted at by the two propositions in the *Kātyāyana Śulvasūtra* (*c.* 500 B.C.) preceding the general theorem of the square of the diagonal of a rectangle (II.8-9). It is evident from Fig. 3.3 that the square *ABCD* is equal to ten elementary squares, four forming the inner square *OPQR* and the remaining six formed of the halves of the four rectangles surrounding it, viz. *AFBO*, *BGCP*, *CHDQ* and *DEAR*, each of which consists of three elementary squares. These can again be divided into two groups: one group consisting of nine elementary squares forming the square on the line *OB* and another group of a single elementary square on the side *OA*. Thus it is proved that $AB^2=OA^2+OB^2$.

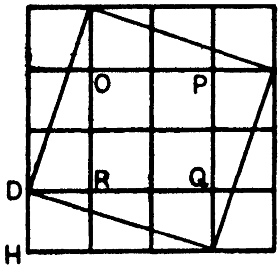


Fig. 3.3

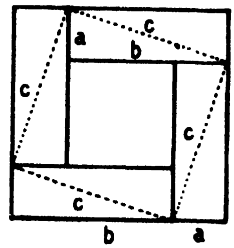


Fig. 3.4

From such instances of rectangles whose lengths and breadths can be represented by commensurable quantities and in which the truth of the theorem is proved easily, one can deduce without any difficulty a general geometrical proof of the theorem. Four rectangles equal to the given one are drawn, each having as its diagonal a side of the square on the diagonal of the given rectangle (Fig. 3.4).

From the above it follows obviously,

$$c^2 = 4(\tfrac{1}{2}ba) + (b-a)^2$$

$$\text{or} \quad c^2 = b^2 + a^2.$$

This proof reappears in the *Bījagaṇita* of Bhāskara II (b. A.D. 1114).

Another plausible hypothesis about the general proof is as follows: Let *ABCD* be a given square. First draw the diagonal *AC* and then extend *AB* to *E* to make *AE* equal to *AC*. Construct the square *AEFG* on *AE*. Join *DE*, and on it construct the square *DHME*. Complete the construction as indicated in Fig. 3.5.

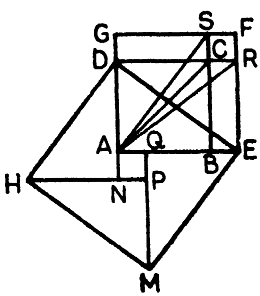


Fig. 3.5

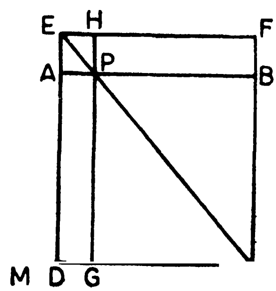


Fig. 3.6

$$\begin{aligned} \text{Now, square } DHME &= 4 \text{ (triangle } DAE) + \text{square } ANPQ \\ &= AERD + ABSG + CRFS \\ &= ABCD + AEFG. \\ \therefore\ DE^2 &= DA^2 + AE^2. \end{aligned}$$

Q.E.D.

In the course of construction of fire-altars, it was necessary to add together or substract from one another two or more figures such as squares, rectangles, and triangles. In the case of the combination of squares, mere application, repeated when necessary, of the theorem of the square of the diagonal was sufficient to get the desired result. But in the case of other figures, they had first to be transformed into squares before the theorem could be applied, and the combined square was then retransformed into the desired shape. The method described in the *Śulvasūtra* for the transformation of a square into a rectangle which will have a given side is very scientific (Fig. 3.6).

Let $ABCD$ be a given square, and M a given length which is greater than a side of the square. Produce DA and CB to E and F respectively so as to make $DE=CF=M$. Join EF. Draw EC cutting AB at P. Through P draw HPG parallel to ED or FC. Then $HFCG$ is the rectangle which is equivalent to the square $ABCD$ and whose side GH is equal to the given length M. For

$$\begin{aligned} \text{triangle } EFC &= \text{triangle } EDC, \\ \text{triangle } EHP &= \text{triangle } EAP, \text{ and} \\ \text{triangle } PBC &= \text{triangle } PGC. \\ \therefore \quad \text{parallelogram } HFBP &= \text{parallelogram } ADGP. \\ \text{Hence parallelogram } HFCG &= \text{square } ABCD. \end{aligned}$$

Q.E.D.

When the given length M is less than a side of the given square $ABCD$, the construction will be as in Fig. 3.7.

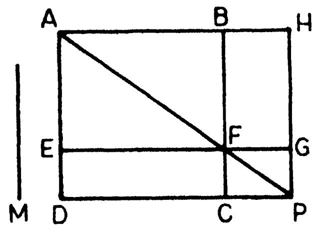


Fig. 3.7

GEOMETRICAL ALGEBRA

Vedic geometry contains the seeds of Hindu geometrical algebra, whose developed form and influence we find as late as in the *Bījagaṇita* of Bhāskara II. It has a solution of the complete quadratic equation:

$$ax^2+bx=c.$$

But its most noteworthy achievements are in the field of indeterminate analysis.[17]

To find a square equal to the sum of a number of other squares of the

[17]Bibhutibhusan Datta, 'The Origin of Hindu Indeterminate Analysis', *Archeion*, Vol. XIII (1931), pp. 401-7; Datta, *Śulva*, pp. 133ff. and 178ff.

same size, Kātyāyana gives a very simple and elegant method in his *Śulvasūtra* (VI.7). 'As many squares (of equal size) as you wish to combine into one, the transverse line will be (equal to) one less than that: twice a side will be (equal to) one more than that, (thus) forming a triangle. Its arrow (altitude) will do that.' That is to say, to combine n equal squares of sides a each, we shall have to form a triangle ABC whose base BC will be equal to $(n-1)\ a$ and $2\ AB=2\ AC=(n+1)a$ (Fig. 3.8).

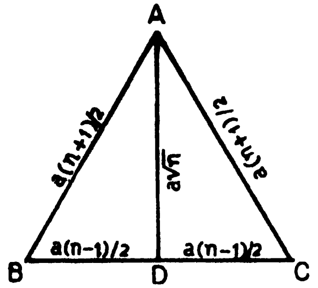


Fig. 3.8

Then if AD be the altitude of the triangle, $AD^2=na^2$.

Thus $\left(\sqrt{n}\right)^2 a^2 + \left(\frac{n-1}{2}\right)^2 a^2 = \left(\frac{n+1}{2}\right)^2 a^2$

Putting m^2 for n in order to make the sides of the right-angled triangle free from the radical, we get

$$m^2a^2 + \left(\frac{m^2-1}{2}\right)^2 a^2 = \left(\frac{m^2+1}{2}\right)^2 .$$

as the solution of the indeterminate equation of the second degree

$$x^2+y^2=z^2.$$

If the sides of the right-angled triangle are to be integral as well as rational, m must be odd. According to Proclus (*c.* A.D. 450), a particular case of this solution where $a=1$ was known to Pythagoras.

Putting $m=5$ and $a=3$ in the above formula, we get the rational rectangle (15, 36, 39) which has been applied in the *Taittirīya Saṁhitā* (VI.2.4.5).

A more general solution of $x^2+y^2=z^2$ is furnished by the Vedic method for the transformation of a rectangle into a square and for the enlargement of a square thus:

$$(2mn)^2+(m^2-n^2)^2=(m^2+n^2)^2$$

It was also known that if $(p,\ q,\ r)$ be a rational solution of the equation $x^2+y^2=z^2$, other rational solutions of it will be given by $(lp,\ lq,\ lr)$, where l is any rational number. Thus the Vedic Hindus obtained the complete general solutions of the rational right-angled triangles. From them they derived

rational right-angled triangles having a given leg. The method is to reduce the sides of any rational right-angled triangle in the ratio of the given leg to the corresponding leg of it. Thus the sides of a rational right-angled triangle having a given leg a will be $\left(a, \frac{aq}{p}, \frac{ar}{p}\right)$, where p, q, r are the sides of any rational right-angled triangle. This method of obtaining rational right-angled triangles having a given leg has been followed in later times in India by Mahāvīra (A.D. 850) and in Europe by Leonardo Fibonacci of Pisa (A.D. 1202) and Vieta (*c.* A.D. 1580).

Solutions of simultaneous indeterminate equations are also found in the *Śulvasūtra*. To indicate how such equations present themselves we take, for example, the case of the *śyena-cit* (falcon-shaped fire-altar). Its total area (at the first construction) is $7\frac{1}{2}a^2$, where a is equal to one *puruṣa*.[18] It is laid down that this fire-altar must be constructed in five layers, each layer consisting of 200 bricks, and that the rifts of bricks in successive layers must not be identical. There is no special injunction about the varieties of bricks to be used or about their relative size. There are different methods of construction of this fire-altar. Baudhāyana has described two methods. In one method four kinds of square bricks are used, while in the second rectangular bricks are also employed. If we take in general the areas of the four varieties of bricks to be $\frac{a^2}{m}$, $\frac{a^2}{n}$, $\frac{a^2}{p}$, and $\frac{a^2}{q}$, and if x, y, z, and u denote respectively the number of bricks of each variety in a layer, we shall have

$$\frac{x}{m} + \frac{y}{n} + \frac{z}{p} + \frac{u}{q} = 7\tfrac{1}{2} \text{ and}$$

$$x + y + z + u = 200.$$

In his *Śulvasūtra* (III.24ff., 41ff.), Baudhāyana states four solutions of these equations as follows:

With constants $m=16$, $n=25$, $p=36$, and $q=100$, the solutions are obtained when

(i) $x=24$, $y=120$, $z=36$, and $u=20$

or (ii) $x=12$, $y=125$, $z=63$, and $u=0$;

and with constants $m=25$, $n = 50$, $p = \frac{50}{3}$, and $q = 100$, the solutions are obtained when

(iii) $x=160$, $y=30$, $z=8$, and $u=2$

or (iv) $x=165$, $y=25$, $z=6$, and $u=4$.

[18] *Puruṣa* means the height or measure of a man (considered as a measure of length).

For the construction of the same altar Āpastamba suggests the use of five different varieties of square bricks.[19] His equations

$$\frac{x}{m}+\frac{y}{n}+\frac{z}{p}+\frac{u}{q}+\frac{v}{r}=7\tfrac{1}{2} \text{ and}$$

$$x+y+z+u+v=200$$

admit of six solutions as follows:

With constants $m=16$, $n=25$, $p=64$, $q=100$, and $r=144$, the solutions are obtained when

(i) $x=67, y=58, z=48, u=18,$ and $v=9$
or (ii) $x=74, y=45, z=52, u=20,$ and $v=9$
or (iii) $x=77, y=42, z=40, u=32,$ and $v=9$;

and with constants $m=16$, $n=25$, $p=36$, $q=64$, and $r=100$, the solutions are obtained when

(iv) $x=12, y=157, z=9, u=0,$ and $v=22$
or (v) $x=70, y=45, z=9, u=56,$ and $v=20$
or (vi) $x=10, y=159, z=9, u=8,$ and $v=14$.

Vedic Hindus knew the elementary treatment of surds. They were aware of the irrationality of $\sqrt{2}$ and attained a very remarkable degree of accuracy in calculating its approximate value[20] as

$$\sqrt{2}=1+\frac{1}{3}+\frac{1}{3.4}-\frac{1}{3.4.34}.$$

In terms of decimal fractions this works out to $\sqrt{2}=1{\cdot}4142156\ldots$. According to modern calculation, $\sqrt{2}=1{\cdot}414213\ldots$. Thus the Hindu approximation is correct up to the fifth place of decimals, the sixth being too great.

There have been various speculations as to how the value of $\sqrt{2}$ was determined in that early time to such a high degree of approximation. Nīlakaṇṭha (A.D. 1500) in his commentary on the *Āryabhaṭīya* opines that Baudhāyana assumed each side of a square to consist of twelve units. Then the square of its diagonal will be equal to 2.12^2. Now,

$$2.12^2 = 288 = 289 - 1 = 17^2 - 1.$$

$$\therefore\ 12.\sqrt{2}=\sqrt{17^2-1}$$

$$=17-\frac{1}{2.17} \text{ approximately.}$$

$$\text{Hence } \sqrt{2}=1+\frac{1}{3}+\frac{1}{3.4}-\frac{1}{3.4.34} \text{ approximately.}$$

[19] *Āpastamba Śulvasūtra*, XI.1ff.; see also Datta, *Śulva*, pp. 184-85.
[20] *Baudhāyana Śulvasūtra*, I.61-62; *Āpastamba Śulvasūtra*, I.6; *Kātyāyana Śulvasūtra*, II.13.

This same hypothesis has been suggested in recent times by Thibaut.[21] We think that the result was arrived at geometrically in the following way[22] (Fig. 3.9):

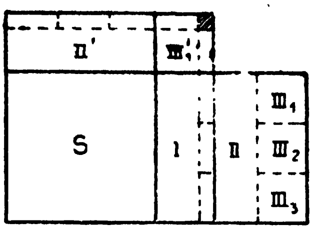


Fig. 3.9

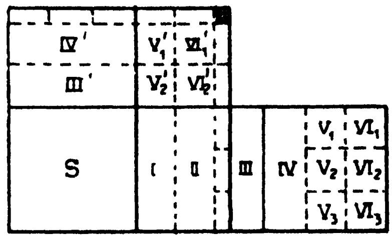


Fig. 3.10

Take two squares whose sides are of unit length. Divide the second square into three equal strips I, II, and III. Subdivide the last strip into three small squares III_1, III_2, and III_3 of sides $\frac{1}{3}$ unit each. Then on placing II and III_1 about the first square *S* in the positions II′ and III_1', a new square will be formed. Now divide each of the portions III_2 and III_3 into four equal strips. Placing the eight strips about the square just formed, on its east and south sides, say, and introducing a small square (marked shaded in the figure) at the south-east corner, a larger square will be formed, each side of which will be obviously equal to

$$1+\frac{1}{3}+\frac{1}{3.4}.$$

This square is clearly larger than the two original squares by an amount $\left(\frac{1}{3.4}\right)^2$, the area of the small (shaded) square introduced at the corner. So to get equivalence, cut off from the sides of the former square two thin strips. If x be the breadth of each thin strip, we must have

$$2x\left(1+\frac{1}{3}+\frac{1}{3.4}\right)-x^2=\left(\frac{1}{3.4}\right)^2$$

whence, neglecting x^2 as being too small, we get

$$x=\frac{1}{3.4.34}\text{ nearly.}$$

[21]G. Thibaut, 'On the Śulvasūtras', *Journal of the Asiatic Society of Bengal*, Vol. XLIV (1875), pp. 239ff.

[22]Datta, *Śulva*, pp. 192ff.

Thus we have finally

$$\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3.4} - \frac{1}{3.4.34} \text{ nearly.}$$

Proceeding in the same way we easily get an approximate value of

$\sqrt{3}$, namely, $\sqrt{3} = 1 + \frac{2}{3} + \frac{1}{3.5} - \frac{1}{3.5.52}$ nearly (Fig. 3.10).

This approximate value can be obtained by the method of Nīlakaṇṭha thus:

$$\begin{aligned}\sqrt{3} &= \frac{1}{15}\sqrt{3.15^2} \\ &= \frac{1}{15}\sqrt{26^2-1} \\ &= \frac{1}{15}\left(26 - \frac{1}{2.26}\right) \text{ nearly} \\ &= 1 + \frac{2}{3} + \frac{1}{3.5} - \frac{1}{3.5.52} \text{ nearly.}\end{aligned}$$

ARITHMETIC

Sources of information on Vedic arithmetic being very meagre, it is difficult to define the topics for discussion and their scope of treatment. One problem that appears to have attracted the attention and interest of Vedic Hindus was to divide 1,000 into 3 equal parts. According to tradition, only the gods Indra and Viṣṇu succeeded in solving it. And for that they have been extolled highly in Vedic literature. The earliest reference to this purported achievement of Indra and Viṣṇu is found in the *Ṛg-Veda* (VI.69.8). It is mentioned also in other works.[23] Thus the *Taittirīya Saṁhitā* (III.2.11.2) says:

> Ye twain have conquered; ye are not conquered;
> Neither of the two of them hath been defeated;
> Indra and Viṣṇu, when ye contended,
> Ye did divide the thousand into three.

It is unknown how the problem could have been solved, for 1,000 is not divisible by 3. So an attempt has been made to explain away the whole thing as a metaphorical statement. But a passage in the *Śatapatha Brāhmaṇa* (III.3.1.13) seems clearly to belie all such speculations, saying: 'When Indra and Viṣṇu divided a thousand into three parts, one remained in excess, and that they caused to be

[23] *Atharva-Veda*, III.44.1; *Maitrāyaṇī Saṁhitā*, II.4.4; *Śatapatha Brāhmaṇa*, III.3.1.13.

reproduced into three parts. Hence even now if any one attempts to divide a thousand by three, one remains over.' In any case it was a mathematical exercise.

Vedic Hindus developed the terminology of numeration to a high degree of perfection. The highest terminology that ancient Greeks knew was 'myriad' which denoted 10^4 and which came into use only about the fourth century B.C. The Romans had to remain content with a 'mille' (10^3). But centuries before them the Hindus had numerated up to *parārdha* (10^{14}) which they could easily express without ambiguity or cumbrousness. The whole system is highly scientific and is very remarkable for its precision.

From the time of the Vedas the Hindus adopted the decimal scale of numeration. They coined separate names for the notational places corresponding to 1, 10, 10^2, 10^3, 10^4, 10^5, etc., and any number, however big, used to be expressed in terms of them. But in expressing a number greater than 10^3 (*sahasra*) it was more usual to follow a centesimal scale. Thus 50.10^3 was a more common form than 5.10^4. For instance, we find *ṣaṣṭiṁ sahasrāṇi*[24] (60.10^3), *pañcāśat sahasram*[25] (50.10^3), and *dvā-saptatiḥ sahasrāṇi*[26] (72.10^3). Even such forms as $x.10^2$ are not wanting, as, for example, *ṣaṣṭiḥ śata*[27] (60.10^2). Though the term for the sixth denomination is *niyuta* in Vedic literature (except in the *Kāṭhaka Saṁhitā*), it was often called *śata-sahasra* (100.10^3, i.e. hundred thousand). In the *Taittirīya Upaniṣad* (II.8) the centesimal scale has been adopted in describing the different orders of bliss. *Brahmānanda*, or the bliss of Brahman, has been estimated as 100^{10} times the measure of one unit of human bliss.

In cases of actual measurements the Hindus often followed other scales. For instance, we have in the *Śatapatha Brāhmaṇa* (XII.3.2.5 *et seq.*) the minute subdivision of time on the scale of 15. The smallest unit *prāṇa* is given as $\frac{1}{15^5}$ of a day.[28] In the *Vedāṅga-jyotiṣa* (verse 31) a certain number is indicated as *eka-dvi-saptika*. If it really means 'two-sevenths and one' as it seems to do, then it will have to be admitted that there was once a septisimal scale.[29]

The whole vocabulary of the number-names of the Vedic Hindus consisted mainly of thirty fundamental terms which can be divided into the following three groups:

(i) *eka, dvi, tri, catur, pañca, ṣaṭ. sapta, aṣṭa,* and *nava;*

(ii) *daśa, viṁśati, triṁśat, catvāriṁśat, pañcāśat, ṣaṣṭi, saptati, aśīti,* and *navati;* and

[24] *Ṛg-Veda*, I.53.9; *Śatapatha Brāhmaṇa*, X.2.1.11, XIII.4.1.6, etc.

[25] *Ṛg-Veda*, IV.16.13.

[26] *Bṛhadāraṇyaka Upaniṣad*, II.1.19.

[27] *Ṛg-Veda*, VII.18.14.

[28] The *Śāṅkhāyana Śrautasūtra* (XIV.75 *et seq.*) has a decimal subdivision of the day. Cf. *Śāṅkhāyana Āraṇyaka*, VII.20.

[29] Centesimal and septisimal scales are found in the Buddhist work *Lalitavistara*, X.

(iii) *śata, sahasra, ayuta, niyuta, prayuta, koṭi, arbuda, nyarbuda, samudra, madhya, anta,* and *parārdha.*

In (i) each term stands for a number which is greater by unity than the number denoted by the term preceding it; in (ii) each term stands for a number greater by 10 than the preceding term; and in (iii) each term is numerically 10 times as great as the preceding term. The name of any other number is formed by a combination of the above terms in a well-defined and well-regulated manner. It should be pointed out that all authorities agree about the names and their order in (i) and (ii). But in (iii) there is agreement only up to the term *ayuta* (10,000); after that there are variations either by the interchange of terms or by the introduction of one or two new terms.[30] As pointed out by Pāṇini (*c.* fifth century B.C.) in his *Aṣṭādhāyī* (V.1.59), all the number-names in (ii) except the first one (*daśa*) are formed on a multiplicative principle. Thus *viṁśati* (20) equals *dvau daśatau* (2×10); *triṁśat* (30) equals *trayo daśatāḥ* (3×10); and so on.

The compound name for a number below 100 is formed by two words, one from each of (i) and (ii). The term from (i) generally precedes that of (ii). Thus we have *ekā-daśa* (11), *sapta-viṁśati* (27), *aṣṭā-triṁśat* (38), etc. In a compound number-name of this class, the principle involved is that of addition.[31] But in certain special cases the principle of subtraction is also in evidence. Thus 19 is called *nava-daśa* (literally, $9+10$) or *ekānna-viṁśati* (literally, $20-1$). Similarly, we get such names as *nava-viṁśati* ($9+20$) or *ekānna-triṁśat* ($30-1$), and *nava-navati* ($9+90$) or *ekānna-śata* ($100-1$). The principle of subtraction is found from the earliest Vedic age. It occurs alternately with the principle of addition in the *Taittirīya Saṁhitā* (VII.2.11) in an interesting way: *ekānna-viṁśati, nava-viṁśati, ekānna-catvāriṁśat, nava-catvāriṁśat,* and so on. In later times, however, the terms *nava-daśa, nava-viṁśati,* etc. became obsolete and the terms involving the principle of subtraction were retained. In these, again, the prefix *ekānna* changed to *ekona* ('one less'), so that we get only such forms as *ekona-viṁśati* and *ekona-triṁśat*. Sometimes even the numerical prefix *eka* is deleted and we have *una-viṁśati* etc.

The facts just mentioned will belie, at least so far as the terminology is concerned, the remark of Cajori that the principle of subtraction was not used by any other people before the old Etruscans of Italy.[32] It was, in fact, applied by the ancient Hindus not less than two millennia before them.

In the formation of number-names above 100, which requires the use of the terms from (iii), two principles are mainly in evidence: that of multiplicatior and that of addition. We have already noticed that the multiplicative principl

[30] Macdonell and Keith, *op. cit.*, pp. 342-43.
[31] *Aṣṭādhyāyī*, V.2.44-45, VI.3.47.
[32] F. Cajori *History of Mathematics* (New York, 1922), p. 63.

is present, more or less covertly, in the formation of number-names in (ii), except the first one. When a small number is placed *before* a term of higher denomination, the latter is to be multiplied by the former, but when placed *after*, it is to be added.[33] Thus it became necessary to stick to a definite order of arranging the terms of compound number-names representing large numbers. The usual practice from the earliest time was to put the term of higher denomination first, except in the case of the two lowest denominations where the reverse was usually followed. Thus we find such illustrations as *sapta śatāni viṁśatiḥ* (720), *sahasrāṇi śatā daśa* (1,110), and *ṣaṣṭiṁ sahasrā navatiṁ nava* (60,099) in the *Ṛg-Veda*.[34]

As regards the numeral symbolism, we are almost completely in the dark because of inadequate palaeographic records. Some evidence of the existence of Vedic numeral symbolism can be gathered, however, from literary sources. A passage in the *Ṛg-Veda* (X.62.7) identifies some cows by the qualifying epithet *aṣṭa-karṇī*. It obviously means 'having (the sign for the number) 8 marked on the ear'.[35] The *Kāṭhaka Saṁhitā* (XIII.10) mentions a certain gold weight called *aṣṭā-pruḍḍhiraṇyam* or *aṣṭā-mṛdaṁ hiraṇyam*. Both these expressions have the identical meaning of 'a piece of gold having (the sign for the number) 8 impressed on it'.[36]

The seals and inscriptions of Mohenjo-daro show that in the third millennium before the Christian era numbers were represented in the Indus valley by means of vertical strokes arranged side by side or one group upon another. There were very probably other signs for bigger numbers. Those rudimentary and cumbrous devices of rod-numerals were, however, quite useless for the representation of large numbers mentioned in the Vedas. In making calculations with such large numbers, as large as 10^{12}, Vedic Hindus must have found the need for some shorter and more rapid method of representing numbers. This and other considerations give sufficient grounds for concluding that Vedic Hindus had developed a much better system of numerical symbols. An ancient story narrated in the *Mahābhārata* (III.132-34) states that 'the signs of calculation (that is, numeral signs) are always only nine in number' (III.134.16). This

[33]Exceptions to this general rule and other peculiarities in the formation of number-names have been noted in the author's article 'Aṅkānāṁ vāmato gatiḥ' in *Sāhitya Pariṣad Patrikā* (1337 B.S.), pp. 70-80.

[34]I.164.11; II.1.8; and I.53.9 respectively.

[35]This obvious interpretation of the term *aṣṭa-karṇī* has been disputed by some modern oriental scholars without sufficient ground. But it is supported by other similar epithets, e.g. *karkarī-karṇyaḥ* (having the mark of a lute on the ear), *dātra-karṇyaḥ* (having the mark of a sickle on the ear), and *sthūṇā-karṇyaḥ* (having the mark of a stake on the ear), which are found in the *Maitrāyaṇī Saṁhitā* (IV.2.9). See Macdonell and Keith, *op. cit.*, pp. 45-46; and Zimmer, *Altindisches Leben*, pp. 234 and 348.

[36]The lengthening of the terminal vowel *a* of *aṣṭa* into *ā* as occurs in the compounds *aṣṭā-pruth* and *aṣṭā-mṛdam* in Vedic grammar is found in many cases, e.g. *aṣṭā-kapālam* and *aṣṭā-padīm*. The root *pruth* means 'to employ force', and *mṛd*, 'to press upon'. Hence the radical significance of the compounds *aṣṭā-pruth* and *aṣṭā-mṛdam* is 'having (the sign for the number) 8 impressed upon'.

story mentions the names of Uddālaka, Śvetaketu, Aṣṭāvakra, and Janaka, who figure also in the Upaniṣads. If it is accepted that these names demonstrate the truly ancient character of that story, it becomes clear that the decimal place-value system of numeral notation was known to the Hindus of the Brāhmaṇa period.

From a reference in the *Aṣṭādhyāyī* of Pāṇini we come to know that the letters of the alphabet were used to denote numbers. Another favourite device of Vedic Hindus to indicate a particular number was to employ the names of things permanently connected with that number by tradition or other associations, and sometimes *vice versa*. Applications of this are found in the earliest Saṁhitās. This practice of recording numbers with the help of letters and words became very popular in later times, especially amongst astronomers and mathematicians.

It appears that Vedic Hindus used to look upon some numbers as particularly holy.[37] One such number is 3. In the *Ṛg-Veda* the gods are grouped in three (I.105.5) and the mystical 'three dawns' are mentioned (VIII.41.3, X.67.4). Cases of magic where 3 is employed in a mysterious occult manner occur in the *Ṛg-Veda* (VIII.91.5-7, X.87.10ff.) and the *Atharva-Veda* (IV.3.1, 9.8). Even the number 180 is mentioned in the *Ṛg-Veda* as three sixties (VIII.96.8) and 210 as three seventies (VIII.19.37). The number regarded as most sacred seems to have been 7. Thus in the *Ṛg-Veda* we get 'seven seas' (VIII.40.5), 'seven rays of the sun' (I.105.9), and 'seven sages' (IV.42.8, IX.92.2, etc.); and the number 49 is stated as seven sevens. Instances of combinations of these two numbers also occur. Thus 21 is stated as three sevens in the *Ṛg-Veda* (I.133.6, 191.12) and the *Atharva-Veda* (I.1.1), and 1,470 as three seven seventies in the *Ṛg-Veda* (VIII. 46.26).

Numbers were divided into even (*yugma*, literally 'pair') and odd (*ayugma*, literally 'not pair'), but there is no reference to further subdivisions of numbers. There is an apparent reference to zero and recognition of the negative number in the *Atharva-Veda*. Zero is called *kṣudra* (XIX.22.6), meaning 'trifling'; the negative number is indicated by the epithet *anṛca* (XIX.23.22), meaning 'without a hymn'; and the positive number by *ṛca* (XIX.23.1), meaning 'a sacred verse'. These designations were replaced in later times by *ṛṇa* (debt) and *dhana* (asset).

Vedic Hindus became interested in numbers forming series or progressions. The *Taittirīya Saṁhitā* (VII.2.12-17) mentions the following arithmetical series:

(i) 1, 3, 5, ... 19, 29, 39, ...99;
(ii) 2, 4, 6, ... 100;
(iii) 4, 8, 12, ... 100;

[37] E. W. Hopkins, 'Numerical Formulae in the Veda and their Bearing on Vedic Criticism', *Journal of the American Oriental Society*, Vol. XVI (1894), pp. 275-81.

(iv) 5, 10, 15, ... 100; and

(v) 10, 20, 30, ... 100.

The arithmetical series are classified into *ayugma* and *yugma*. The *Vājasaneyi Saṁhitā* (XVIII.24.25) has given the following two instances:

(i) 1, 3, 5, ... 31 and

(ii) 4, 8, 12, ... 48.

The first series occurs also in the *Taittirīya Saṁhitā* (IV.3.10). The *Pañcaviṁśa Brāhmaṇa* (XVIII.3) describes a list of sacrificial gifts forming a geometrical series of some interest:

12, 24, 48, 96, 192, ... 49152, 98304, 196608, 393216. This series reappears in the Śrauta-sūtras.

Some method for the summation of series was also known. Thrice the sum of an arithmetical progression whose first term is 24, the common difference 4, and number of terms 7 is stated correctly in the *Śatapatha Brāhmaṇa* (X.5.4.7) as 756. That is to say,

$$3\ (24+28+32+\dots \text{ to 7 terms}) = 3\times\frac{7}{2}\{2\times 24+(7-1)\times 4\} \quad =756.$$

In the *Bṛhaddevatā* (III.13) we find the summation: $2+3+4+\dots 1000=500499$. From the method indicated by Baudhāyana for the enlargement of a square by successive additions of gnomons, it is evident that he knew the result:

$$1+3+5+\dots+(2n+1) = (n+1)^2.$$

Vedic Hindus knew how to perform fundamental arithmetical operations with elementary fractions. For example, we take the following results from the *Śulvasūtra*:[38]

$$7\tfrac{1}{2} \div \frac{1}{25} = 187\tfrac{1}{2},$$

$$\left(2\frac{2}{7}\right)^2 + \left(\frac{1}{2}+\frac{1}{12}\right)\left(1-\frac{1}{3}\right) = 7\frac{1}{2}, \text{ and}$$

$$\sqrt{7\frac{1}{9}} = 2\frac{2}{3}$$

They dealt also with a fraction of a fraction, e.g.

$$7\tfrac{1}{2} \div \frac{1}{15} \text{ of } \tfrac{1}{2} = 225.$$

We have seen that Vedic Hindus contributed directly towards the growth and development of mathematics. In certain respects they anticipated the work of the great mathematicians of later days. Their indirect contribution to the subject through their immediate followers and disciples was also considerable.

[38]See Datta, *Śulva*, pp. 212ff.

4

POST-VEDIC MATHEMATICS

THE development of a certain level of mathematical knowledge dictated by the material needs of a society is a common phenomenon of all civilizations. What is noteworthy is that Vedic Hindus went much farther than what was warranted by such needs and developed a natural love for the subject fully in keeping with their propensity for abstract reasoning. That is why we find them preoccupied with large numbers, problems of irrational quantities and elementary surds, indeterminate problems and equations, arithmetical and geometrical series, and the like, while engaged in the practical design and construction of sacrificial altars. Although problems of architecture, the intricacies of the science of language such as metre and rhyme, and commercial accounting did stimulate the development of mathematics, its greatest inspiration doubtless came from the consideration of problems of reckoning time by the motions of celestial bodies. In India, as elsewhere, a substantial part of mathematics developed as a sequel to astronomical advancement; and it is no accident that the bulk of post-Vedic mathematics has been found only in association with the Siddhāntas, a class of astronomical works. The formative period of Siddhāntic astronomy may be limited to the first few centuries of the Christian era; for in the fifth and sixth centuries A.D. there appeared Āryabhaṭa's works and Varāhamihira's summary of a number of astronomical Siddhāntas written before his time. These centuries and possibly the few closing ones of the pre-Christian era witnessed the development of mathematics required for adequately expressing, describing, and accounting for astronomical elements and phenomena, as well as for meeting the various needs of an organized society.[1]

Jaina priests showed remarkable interest in the study and development of mathematics. They devoted one of the four branches of Anuyoga (religious literature) to the elucidation of *gaṇitānuyoga* (mathematical principles) and prescribed proficiency in *saṁkhyāna* (science of calculation) and *jyotiṣa* (astronomy) as an important prerequisite of the Jaina priest.[2] An idea as to the various mathematical topics discussed at this early age and recognized in later Jaina mathematical works such as the *Gaṇitasāra-saṅgraha* of Mahāvīra (*c.* A.D. 850) and *Gaṇitatilaka* of Śrīpati (A.D. 999) may be obtained from an extant passage (*sūtra* 747) in the *Sthānāṅga-sūtra* (*c.* first century B.C.). This

[1]Mahāvīra gives an interesting account of the application of mathematics to the various fields of human thought and action in the *Gaṇitasāra-saṅgraha*, 1.9-19.

[2]*Bhagavatī-sūtra* *sūtra* 90; *Uttarādhyāyana-sūtra*, XXV.7,8, and 38.

passage enumerates: *parikarma* (fundamental operations), *vyavahāra* (determination), *rajju* (geometry—this term, synonymous with the *śulva* of the Vedic Śulvasūtras, was replaced by the term *kṣetragaṇita*, meaning geometry), *rāśi* (heap—includes mensuration of solid bodies), *kalāsavarṇa* (fraction), *yāvat-tāvat*[3] (linear equation), *varga* (quadratic equation), *ghana* (cubic equation), *varga-varga* (biquadratic equation), and *vikalpa* (permutations and combinations).

It will be seen that *gaṇita* then comprised all the three principal branches, viz. arithmetic, algebra, and geometry. Its differentiation into arithmetic (*pāṭīgaṇita* or *vyaktagaṇita*) and algebra (*bījagaṇita*, *avyaktagaṇita*, or *kuṭṭaka*) did not take place until Brahmagupta (b. A.D. 598) sought to emphasize the importance of the two. Treatises exclusively devoted to arithmetic began to appear from about the eighth century A.D.[4] Geometry, which had a somewhat independent career at the time of the composition of the Śulvasutras, formed part of *gaṇita* and later became largely associated with arithmetic.

ARITHMETIC

Decimal Place-value Numeration: It is well known that the development of arithmetic largely centred round the mode of expressing numbers. Before the adoption of numerals with positional values, its progress was everywhere tardy and halting, as in the case of Greek or Roman arithmetic with its cumbersome mode of expressing numbers. The early advantage, skill, and excellence attained by Indians in this branch of mathematics were primarily due to their discovering the decimal place-value concept and notation, that is, the system of expressing any number with the help of either groups of words or ten digits including zero having place-value in multiples of ten. An extensive literature exists on the Indian method of expressing numbers, particularly on the decimal place-value notation with zero, and on the question of its transmission to South and West Asia and to Europe leading to its international adoption. Mathematicians and orientalists are generally agreed that the system with zero originated in India and thence travelled to other parts of the world. 'Our numerals and the use of zero', observes Sarton, 'were invented by the Hindus and transmitted to us by the Arabs (hence the name Arabic numerals which we often give them).'[5] In the beginning of the present century a few scholars, notably George Rusby Kaye and Baron Carra de Vaux, disputed the general view by questioning the reliability of Indian as well as Arabic

[3]See Bibhutibhusan Datta's article in *Bulletin of the Calcutta Mathematical Society* (*BCMS*), Vol. XXI (1929), p. 122.

[4]The Bakhshali Manuscript, whose principles appear to have been developed, as believed by Hoernle, Datta, and others, about A.D. 200, is primarily a work on arithmetic.

[5]George Sarton, *The Appreciation of Ancient and Medieval Science During the Renaissance: 1450-1600* (Philadelphia University and Pennsylvania Press, 1955), p. 151.

literary traditions on grounds of chronological uncertainty and on differing philological interpretations of terms like *hindasī* and sought to trace the origin to Greek sources. Their objections and criticisms were, however, adequately answered by both mathematicians and oriental scholars such as Clark, Datta, Ganguly, Das, and Ruska.

But the knowledge derived during the last thrity years or so from the study of Babylonian mathematical cuneiform texts by Neugebauer, Sachs, and others, and from recent studies of Chinese mathematics by Joseph Needham and his co-workers calls for a review of the question of origin and development of the system with reference to the role of India. The system of numeration in the mathematical cuneiform texts of the Old-Babylonian period (1600 B.C.) has been shown to be based on place-value notation, albeit on a sexagesimal scale, which Neugebauer believes spread to the Greeks and then to the Hindus who contributed the final step, namely, the use of the place-value notation for the smaller decimal units.[6] Needham claims that the Shang oracle bone numeral forms (1400-1100 B.C.) and the method of writing numbers with them are based on the decimal place-value idea continued in the rod numerals, and suggests the possibility of the discovery of zero in South-East Asia (Indo-China and Java) where Hindu culture 'met the southern zone of the culture of the Chinese'.[7] He further thinks 'that the "emptiness" of Taoist mysticism, no less than the "void" of Indian philosophy, contributed to the invention of a symbol for *śūnya*,[8] i.e. the zero'.

In examining the question of India's contribution to the origin and development of the place-value system with zero, the basic facts established from literary and epigraphic sources may be summarized as follows:

(a) From the Vedic times the basis of numeration in India has consistently been ten. Long lists of names for several decimal places are found in the sacred literatures of the Hindus, Jains, and Buddhists. The *Vājasaneyi* (XVII.2), *Taittirīya* (IV.4.11.4; VII.2.20.1), *Maitrāyaṇī* (II.8.14), and *Kāṭhaka* (XVII. 10) *Saṁhitās* give denominations up to 13 places (10^{12}), e.g. *eka* (1), *daśa* (10), *śata* (10^2), *sahasra* (10^3),...*samudra* (10^9), *madhya* (10^{10}), *anta* (10^{11}), and *parārdha* (10^{12}). Buddhist literature continued the same tradition and introduced a centesimal scale (*śatottara-gaṇanā*), obtaining the name *tallakṣaṇa* for the 54th place (10^{53}).[9] The Jains in the *Anuyogadvāra-sūtra* (*c.* 100 B.C.) called the decimal places *gaṇanā-sthāna*, gave a numerical vocabulary analogous to that of the Brāhmaṇic literature, and mentioned fantastically large numbers up to 29 places and beyond. By their conception of a time-scale called *śīrṣa-prahelikā*

[6] O. Neugebauer, *The Exact Sciences in Antiquity* (Copenhagen, 1951), p. 20.
[7] Joseph Needham, *Science and Civilisation in China*, Vol. III (Cambridge, 1959), p. 11.
[8] *Ibid.*, p. 12.
[9] *Lalitavistara*, ed. R. L. Mitra (Calcutta, 1877), p. 168.

8,400,000) which they increased to higher powers, they mentioned a number equal to $8{,}400{,}000^{28}$.[10] Thus the decimal place-value mode of reckoning was recognized without any ambiguity in the sacred literatures of the pre-Christian period going back to the time of the composition of the Saṁhitās. This mode of reckoning we find more clearly stated in the mathematical-astronomical texts from Āryabhaṭa onwards in such expressions as *sthānātsthānaṁ daśaguṇaṁ syāt* (from one place to the next it should be ten times)[11] and *daśaguṇottarāḥ saṁjñāḥ* (the next one is ten times the previous).[12]

(b) The word-numerals and their use in a decimal place-value arrangement represent another unique development in India, designed particularly to compress a large mass of numerical data into versified mathematical texts. The word-names were selected by considering their association with numbers. Thus 0 (zero) was denoted by *kha*, *ākāśa*, *ambara*, *śūnya*, and their various synonyms, signifying 'emptiness', 'void', 'nothingness', etc.; 1 by earth synonyms, e.g. *kṣiti*, *dharā*, *pṛthivī*, or moon synonyms, e.g. *indu*, *candra*, *abja*; 2 by *yama*, *aśvin*, *dasra*, *akṣi*, etc.; 3 by *rāma*, *guṇa*, *agni*, etc.; 4 by *veda*, *samudra*, *arṇava*, etc.; and so on.[13] Fabrication of word-numerals may be traced to the *Ṛg-Veda* (VII.103.1), and their use without place-value has been found in the *Śatapatha* (XIII.3.2.1) and *Taittirīya Brāhmaṇas* (I.5.11.1), the *Vedāṅga-jyotiṣa* (*Ārṣa*, 4, 19, 31; *Yājuṣa*, 13, 20, 23, 25), and some Sūtra texts. Their use in a decimal system appears in the *Agni Purāṇa* and *Pañca-siddhāntikā* (*c.* sixth century A.D.). The place-value of a word-numeral for any number used in the 1st, 2nd, 3rd,...etc. places will be expressed by multiplying the word-numeral by 1, 10, 100,...etc. respectively. These are written from right to left in accordance with the principle *aṅkānāṁ vāmato gatiḥ* (numerals move to the left). A few examples are given from the *Pañca-siddhāntikā* (I.14, 17; IX.2, 3):

	1 2 3 4 5 6 7	7 6 5 4 3 2 1
(i)	*nava -vasu -guṇa -rasa -rasāḥ*	6 6 3 8 9
(ii)	*śara -nava -kha -indriya-arṇava-āśāḥ*	1 0 4 5 0 9 5
(iii)	*muni -yama -yama-dvi*	2 2 2 7
(iv)	*śūnya-dvi -pañca -yama*	2 5 2 0
(v)	*svara-eka -pakṣa-ambara -svara -ṛtu*	6 7 0 2 1 7
(vi)	*rasa -viṣaya-guṇa -ambara -ṛtu -yama-pakṣa*	2 2 6 0 3 5 6

Notice how in the above examples the word-numeral *yama* or *pakṣa*, meaning 2 when used to denote a numerical figure, represents the numbers 20, 200,

[10]Bibhutibhusan Datta, 'Place-value System of Notation', *BCMS*, Vol. XXI (1929), pp. 138-40.

[11]*Gaṇitapāda*, verse 2.

[12]*Līlāvatī*, verses 10-11.

[13]Bibhutibhusan Datta and Avadesh Narayan Singh, *History of Hindu Mathematics*, Part I (Asia Publishing House, Bombay, 1962), pp. 54-55; Louis Renou and Jean Filliozat, *L'Inde classique* (Hanoi, 1953), pp. 708-9.

2000, 200000, and 2000000 when used in the 2nd, 3rd, 4th, 6th, and 7th places respectively.

The word-numerals were also used in inscriptions, of which the earliest records occur in Cambodia, Campā, and Java. A few examples are given below.[14]

(i) *Stone inscription of Phnoṁ Bāyān, Cambodia* (A.D. 604):
6 2 5
rasa-dasra-śaraiś-śakendravarṣe = in the year 526 of the Śaka king, i.e. 526 Śaka.

(ii) *Stone inscription of Mi-son, Campā* (A.D. 609):
9 7 5
nava-saptatyuttarapañca varṣaśatātīta śakā-vanīndra-kālaparimāṇam = in the Śaka epoch 579, i.e. 579 Śaka.

(iii) *Stone inscription of Kangal, Java* (A.D. 732):
4 5 6
śakendra tigate śrutīndriyarasairaṅgīkṛte vatsare = in the year of the Śaka king expressed by the number 654, i.e. 654 Śaka.

In the aforesaid regions of South-East Asia, the word-numerals were soon followed by numerals with zero and decimal place-value to express Śaka dates. This will be further discussed in what follows.

(c) Āryabhaṭa I (b. A.D. 476) invented a system of expressing numbers with the help of consonants and vowels, based again on the decimal place-value principle. The need for extreme compactness and brevity in using a large number of astronomical constants in verses with due regard to metrical considerations led to this interesting method, explained in the *paribhāṣā* stanza of his *Daśagītikā-sūtra*. In this system, 25 *varga* letters from *ka* to *ma* have values from 1 to 25, and 8 *avarga* letters from *ya* to *ha* have values from 3 to 10. Their places are governed by nine vowels from *a* to *au*, the distinction between short and long vowels being disregarded. The place-values for vowels, however, differ for *varga* and *avarga* letters. Thus the expression *khyughṛ* means:[15]

$$\begin{aligned} khyughṛ &= khu + yu + ghṛ \\ &= 2\times 10^4 + 3\times 10^5 + 4\times 10^6 \\ &= 4{,}320{,}000. \end{aligned}$$

At about the same time a similar but somewhat improved system of alphabetical notations called *kaṭapayādi* was developed and used in mathematical-astronomical texts.[16] The system, employing place-value, was known to

[14] G. Coedès, '*A propos de L'origine des chiffres arabes*', *Bulletin of the School of Oriental Studies*, Vol. VI (London Institute, 1930-32), pp. 323-28.

[15] S. N. Sen, 'Āryabhaṭa's Mathematics', *Bulletin of the National Institute of Sciences of India*, No. XXI (1963), pp. 298-302. See also J. F. Fleet, 'Āryabhaṭa's System of Expressing Numbers' *Journal of the Royal Asiatic Society* (*JRAS*), 1911, pp. 109-26.

[16] J. F. Fleet, 'The Kaṭapayādi System of Expressing Numbers', *JRAS* (1911), pp. 788-94.

Āryabhaṭa I; it was used by Bhāskara I (*c.* A.D. 574) and Āryabhaṭa II (A.D. 950), and applied in the astronomical *Jaimini-sūtras* (I.2.2) of unknown date.

(d) There are several references to zero in literary works before its appearance in inscriptions and texts in association with numerals. As already stated, zero appears in word-numerals where it means 'emptiness' or 'void'. In Piṅgala's (*c.* 200 B.C.) *Chandaḥ-sūtra* (VIII.29-31) zero is mentioned in the rules for calculating the number of long and short syllables in a metre of *n* syllables. The Bakhshali Manuscript (*c.* A.D. 200)[17] uses zero in calculation and represents it by a dot as does the Kashmir recension of the *Atharva-Veda.* The Sanskrit name for this zero-dot is *śūnya-bindu*, as is clearly stated in Subandhu's *Vāsavadattā* (*c.* A.D. 600): 'The stars shone forth, ... like ciphers because of the nullity of metempsychosis, scattered in the sky as if on the ink-black skin rug of the Creator who reckoneth the sum total with a bit of the moon for chalk.'[18] Apart from the synonym, the passage indicates the use of dot to represent zero in mathematical calculations. In the Śrīvijaya inscriptions of Palembang in Sumatra, a dot is used in writing the zero of the number 605. The early Arab writers on the Hindu numeral system, such as Ibn Wahshiya (*c.* A.D. 855) and Al-Nadim (*c.* A.D. 987), used dots to represent zero. The Hindu term for zero—*śūnya,* meaning 'void'—passed over into Arabic as *as-sifr* or *si fr* whose various Latinized versions were *ciffre, ziffre* (*Liber algorismi*), *zephirum* (*Liber abaci*), *cifra, figura nihili* (*Sacrobosco*), *tziphra* (*Maximus planudes*), *circulus* (*Algoritmi de numero Indorum*), and a few others.[19]

(e) The Kharoṣṭhī numerals are found to occur in the Aśokan, Śaka, Parthian, and Kuṣāṇa inscriptions dating from the fourth century B.C. to the second century A.D. Strokes and crosses were used for the first eight digits.

1	2	3	4	5	6	7	8
I	II	III	X	IX	IIX	IIIX	XX

With the above strokes and crosses and the sign for 10 shown in the following table, numbers were built up to 99 on additive principle. For multiples of 10 up to 100, different symbols were used.

10	20	40	50	80	100

[17]See Bibhutibhusan Datta, 'The Bakhshali Mathematics', *BCMS*, Vol. XXI (1929). pp. 1-60.

[18]...*viśvaṁ gaṇayato dhātuś-śaśi-kaṭhinīkhaṇḍena tamomaṣīśyāme ajina iva saṁsārasyātiśūnyatvāt śūnyabindava iva vilikhitāḥ jagattrayavijigīṣāvinirgatasya makaraketoḥ rati-kara-vikīrṇā... —Vāsavadattā,* trans. Louis H. Gray (New York, 1930), pp. 99-100.

[19]D. E. Smith, *History of Mathematics*, Vol. II (Dover, 1958), p. 71; Suzan Rose Benedict, *A Comparative Study of the Early Treatises Introducing into Europe the Hindu Art of Reckoning* (University of Michigan, 1914).

The multiplicative principle was used in developing symbols for multiples of 100 up to 900. No sign for 1000 is known. The symbols used for 100, 200, and 300 were as shown below.

100 200 300

Intermediate numbers were written on additive principle as shown below:

22 74 122 274

(2+20) (4+70) (2+20+100) (4+70+200)

Where additive principle was applied, numeral symbols were used on the left-hand side, and in the case of the multiplicative principle, on the right-hand side. For writing conjugate numbers the left to right method, similar to the word-numeral arrangement, was followed.

The Brāhmī numerals are more sophisticated in their forms. They have separate signs for numbers 1, 4 to 9, 10 and its multiples up to 90, and for 100, 1,000, etc. Multiples of 100 and 1,000 up to 9,000 are derived on the multiplicative principle, as in the case of the Kharoṣṭhī for multiples of 100. A few examples are given.

Nānāghāṭ:

100 400 700 1,000 4,000 6,000 10,000 20,000

Nāsik: 100 500 1,000 2,000 4,000 8,000

More than thirty inscriptions giving decimal place-value numeral notations are known. A circular symbol for zero appears in the Gwalior inscription of the reign of Bhojadeva in which the verses are numbered from 1 to 26 in decimal figures. In another Gwalior inscription the date Vikrama Saṁvat 933 and the numbers 270, 187, and 50 are given in the decimal place-value system. Those who are reluctant to rely on any evidence other than the palaeographic in such matters have emphasized the importance of the Gwalior inscriptions and cited these as unmistakable proof of the existence in India of a decimal place-value notation with zero.

(f) Curiously enough, decimal place-value numerals with a point symbol (*śūnya-bindu*) as well as a circular symbol for zero appear in three specimens of seventh century inscriptions of Śrīvijaya in the Hindu colonies of South-East Asia — two at Palembang in Sumatra and one in Banka. These give the Śaka dates 605, 606, and 608 in figures. Another old Śrīvijaya inscription found in Sambor gives the Śaka date 605 in the same way. In Java two fragments of inscriptions have been found in Dinaya which express the same date in word-numerals as well as in figures in the decimal place-value arrangement. Thus the Śaka date 682 is written as *nayana-vasu-rasa* and is also repeated in figures.[20]

If one recalls the history of the development of word-numerals in India as discussed in (b), their appearance later on in inscriptions on monuments with Śaka dates in the Hindu colonies of South-East Asia, and the subsequent replacement of word-numerals including zero by figures with a symbol for zero (note also point symbol), it is natural to conclude that the numerals with zero had originated in India and travelled to South-East Asia with the Hindu colonizers. According to Coedès, 'their use in the Indian colonies at such an early date clearly points to their existence in India at a date earlier still'.[21] To suggest that the Chinese decimal place-value system and the emptiness of the Taoist mysticism might have stimulated the discovery of zero in South-East Asia where the Hindu culture met the Chinese can at best be fanciful. Even the claim that the Shang oracle bone forms (fourteenth to eleventh century B.C.) indicate a decimal place-value system is disputable. Much has been made of the multiplicative principle applied in the development of symbols for 100, 200, 500, or for 1,000, 3,000, 4,000, and so on. As we have seen already, the same principle was used in evolving the Kharoṣṭhī symbols for 100, 200, and 300 and the Brāhmī symbols for 100 and its multiples, as well as for 1,000 and its multiples. To express the numbers, say 300, with a symbol is not the same as using the numerical symbol for 3 in the third decimal place and zero in the second and first places or even leaving these places vacant as the Babylonians did. Were it so, the Kharoṣṭhī and the earlier Brāhmī numerals could also claim the dignity of the decimal place-value system.

The Babylonian origin of the place-value system now appears beyond doubt. It is immaterial that they chose a sexagesimal scale. But that the Hindu decimal place-value was derived from the Babylonian sexagesimal place-value cannot be definitely said. The discovery of cuneiform inscriptions of the Hittite kings of Mitanni in Cappadocia (fifteenth to fourteenth century B.C.) and archaeological finds from Ur, Harappa, and Mohenjo-daro have established India's relations with western Asia from the third millennium B.C. There are stray

[20] Coedès, *loc. cit.*

[21] *Leur emploi dans les colonies indiennes a haute époque est nettement en faveur de leur existence dans l'Inde a une époque plus haute encore. Ibid.*

instances of Babylonian sexagesimal parameters appearing in Indian astronomical texts. But the fact that the sexagesimal system was never generally adopted in India, the very ancient and long Indian tradition dating from the Vedic times of giving decimal place-names, and the various experiments of expressing numbers on a decimal place-vlaue plan are nevertheless valid grounds for believing in an independent Indian origin of the decimal place-value notation with zero.

Extraction of Square and Cubic Roots: We have stated that the development of the decimal place-value notation also meant the evolution of a new kind of arithmetic which Sarton describes as a 'medieval novelty'. This 'medieval novelty' expressed through algorism (Arabic decimal notation) came to Europe largely through Arabic translations of, or works based on, Indian treatises and greatly influenced Renaissance mathematics.[22] Let us take the case of the extraction of square and cube roots of large numbers. Theon of Alexandria (*c.* A.D. 390) gave an approximate and algebraical method of extraction of square roots of sexagesimal fractions. The modern arithmetical method even partially did not appear in Europe before Cataneo (A.D. 1546) and, in its entirety, before Cataldi (A.D. 1613), author of the *Trattato*.[23] In India the method first appeared in the *Āryabhaṭīya* (A.D. 499). This was followed by Brahmagupta (b. A.D. 598) who, however, did not give any rule for square root extraction. Subsequently, Mahāvīra (*c.* A.D. 850), Śrīdhara (*c.* A.D. 991), Āryabhaṭa II (*c.* A.D. 950), Bhāskara II (*c.* A.D. 1150), and Kamalākara (A.D. 1658) gave fundamentally the same rules.

The method of extraction of the cube root of any integral number has been traced to the *Gaṇitapāda* of the *Āryabhaṭīya*. The same method is given by Brahmagupta in his *Brāhmasphuṭa-siddhānta* (*Gaṇitādhyāya*, 12.7). Subsequent Indian authors have given the same method in a less cryptic style. Rodet attached special importance to Āryabhaṭa's rules for square and cube root extraction because the very method of dividing the integral numbers in square, non-square, cubic, and non-cubic places indicates the use of decimal place-value notation with zero in Āryabhaṭa's time and possibly even long before his advent.[24] Methods of extraction of square root (*khai fang*) and cube root (*khai li fang*) with the help of abaci or counting boards no doubt appear in the *Chiu-chang Suan-shu* (latter half of the first century A.D.).[25] Smith, in his discussion of the origin of the modern methods of extraction of square and cube roots, overlooked the contribution of Āryabhaṭa and Brahmagupta and mentioned

[22]Suzan Rose Benedict, *op. cit.*; see also Sarton, *op. cit.*

[23]Smith, *op. cit.*, pp. 146-47.

[24]L. Rodet, '*Leçon de Calcul d'Āryabhaṭa*', *Journal Asiatique*, Vol. XIII (1879), pp. 393-434.

[25]Y. Mikami, *The Development of Mathematics in China and Japan*, pp. 13-14; Needham, *op. cit.*, pp. 65-68.

only Bhāskara's rule. Even then he misinterpreted the rule by comparing it with Theon's method.[26] Needham pointed out that the method had appeared in China long before it did in Europe, but he overlooked the work of Āryabhaṭa, Brahmagupta, and others.

ALGEBRA

The beginnings of algebra, or more correctly, the geometrical methods of solving algebraic problems, have been traced to the various *Śulvasūtras* of Āpastamba, Baudhāyana, Kātyāyana, Mānava, and a few others. These problems involving solutions of linear, simultaneous, and even indeterminate equations arose in connection with the construction of different types of sacrificial altars and arrangements for laying bricks for them. The differentiation of algebra as a distinct branch of mathematics took place from about the time of Brahmagupta, following the development of the techniques of indeterminate analysis (*kuṭṭaka*). In fact, Brahmagupta used the terms *kuṭṭaka* and *kuṭṭaka-gaṇita* to signify algebra. The term *bījagaṇita*, meaning 'the science of calculation with elements or unknown quantities' (*bīja*), was suggested by Pṛthūdakasvāmin (A.D. 860) and used with definition by Bhāskara II. The Hindu mathematical literature has various terms for the unknown quantity, e.g. *yāvat-tāvat* (*Sthānāṅga-sūtra*); *yadṛcchā, vāñchā, kāmika* (Bakhshali Manuscript); *gulikā* (*Āryabhaṭīya*); and *avyakta* (*Brāhmasphuṭa-siddhānta, Siddhānta-śekhara*, and *Bhāskarīya-bījagaṇita*).

In the *Sthānāṅga-sūtra*, equations (*samakaraṇa, samīkaraṇa, sadṛśīkaraṇa*, etc.) appear to be classified according to the powers of the unknown quantity, e.g. *yāvat-tāvat* (simple), *varga* (quadratic), *ghana* (cubic), and *varga-varga* (biquadratic). But such classification was not maintained. Brahmagupta gave the following classifications: (1) *eka-varṇa-samīkaraṇa* —equations in one unknown, comprising linear and quadratic equations; (2) *aneka-varṇa-samīkaraṇa* —equations in many unknowns; and (3) *bhāvita* —equations containing products of unknowns. This classification was further elaborated by Pṛthūdakasvāmin and Bhāskara II.

Rule of False Position (*Regula Falsi*): The Rule of False Position, a method of solving simple linear equations of the type $ax+b=0$ by substituting guess values $g1$, $g2$, etc.,[27] was in extensive use among the Arab and European mathematicians in the Middle Ages. In India its traces are noticed in the *Sthānāṅga-sūtra* through the use of the term *yāvat-tāvat*[28] and in the Bakhshali Manuscript.[29] Al-Khwārizmī, Qusta Qusta ibn Luqa, Abu Kamil, and others used a rule called *hisab al-khataayan* in Arabic, which appeared as *el cataym* (Pacioli), *elchataym*,

[26] Smith, *op. cit.*, p. 148.
[27] *Ibid.*, pp. 437-38.
[28] Datta, *op. cit.*, p. 122.
[29] *Ibid.*, pp. 31-32.

etc. in medieval Latin treatises. Smith expressed the view that the rule as used in the Middle Ages had possibly come from India. 'The ordinary rule as used in the Middle Ages', he says, 'seems to have come from India, but it was the Arabs who made it known to European scholars.'[30]

Quadratic Equations: The Śulvasūtras contain problems involving quadratic equations of the types $ax^2=c$ and $ax^2+bx=c$. The Bakhshali Manuscript gives the solution of a problem in a form which reduces to

$$x = \sqrt{\frac{B^2-4AC-B}{2A}}.$$

None of them gives any rule for solving such equations. Both Āryabhaṭa I and Brahmagupta clearly indicate their knowledge of quadratic equations and the solutions thereof. In connection with an interest problem Āryabhaṭa I gave a solution, and the result may be expressed in symbols as follows:

$$x = \frac{-p+\sqrt{p^2+4tpq}}{2t}$$

where p=principal; t=time; q=sum of interest on principal and interest on interest in time t; and x=interest on principal in unit time.

A similar quadratic solution for another interest problem is given in the *Brāhmasphuṭa-siddhānta* (XII.11.15). Such quadratic problems also airse in finding the number of terms (n) in an arithmetical progression. Both Āryabhaṭa I and Brahmagupta give the results correctly which, as Rodet pointed out long ago in the case of the *Āryabhaṭīya*, indicate their knowledge of the solutions of quadratic equations of the form $ax+bx+c=0$.

The method of transforming into a whole square the left-hand side of the quadratic equation $ax^2+bx=c$ by multiplying both sides by $4a$, then adding b^2 on each side, and finally taking the square root for the solution, is given by Śrīdhara in his *Algebra* which is lost. But the method is preserved in quotations in the works of Bhāskara II, Jñānarāja, and Sūryadāsa.

Indeterminate Equations: The branch of algebra dealing with indeterminate equations of the first degree has interested Indian mathematicians and astronomers presumably from the time of the Śulvasūtras. These manuals contain rules and directions which point to the solution of simultaneous indeterminate equations of the first degree. Thus the *Baudhāyana Śulvasūtra* prescribes rules for the construction of a *gārhapatya vedi* (sacrificial fire altar) which lead to indeterminate equations of the following types:

[30] Smith, *op. cit.*, p. 437.

$$x + y = 21$$

$$\frac{x}{m^2} + \frac{y}{n^2} = 1.$$

The results are correctly given, although the procedure is not indicated. Detailed rules of solution are given in the works of Āryabhaṭa I, Brahmagupta, Bhāskara I, Mahāvīra, Āryabhaṭa II, Bhāskara II, and later authors and commentators. Indeterminate analysis had an immediate application in astronomy in the determination of the cycle (*yuga*) of planets from the elapsed cycles of several other given planets.

Āryabhaṭa I and Brahmagupta gave rules for finding the value of N from

$$N = ax + r_1 = by + r_2,$$

which is the same as finding the solution of the indeterminate equation

$$by = ax \pm (r_1 - r_2) = ax \pm c$$

where a and b are called the divisors (*bhāgahāra*), r_1 and r_2 the corresponding remainders (*agra*), and c the difference of remainders (*agrāntara*). Mahāvīra, Āryabhaṭa II, and Bhāskara II chose the form

$$y = \cdot$$

where a was called the dividend (*bhājya*), b the divisor (*hāra*), c the interpolator (*kṣepa*), x the multiplier (*guṇa*), and y the quotient (*phala*). All the authors clearly stated that the equation admits of solution only when a and b are prime to each other. Methods of solving simultaneous indeterminate equations called conjunct pulverizer (*saṁśliṣṭa kuṭṭaka*) of the form

$$by_1 = a_1x \pm c_1$$

$$by_2 = a_2x \pm c_2$$

$$by_3 = a_3x \pm c_3$$

are given by Āryabhaṭa II and Bhāskara II.

The great merit of solving, in rational integers, indeterminate equations of the second degree having the general forms

$$Nx^2 \pm c = y^2$$

$$Nx^2 \pm 1 = y^2$$

belongs to Brahmagupta. Further refinements, clarifications, and extensions were due to subsequent Indian mathematicians such as Śrīpati, Bhāskara II, and Nārāyaṇa, and several commentators who made no mean contribution to this branch of algebra. Hankel, the well-known historian of mathematics, was not exaggerating the achievement of the Hindu mathematicians in this field when he observed: 'It is above all praise; it is certainly the finest thing which was achieved in the theory of numbers before Lagrange.'[31]

Hindu mathematicians call indeterminate equations of the second degree *varga-prakṛti* (square-nature), in which N is termed *guṇaka-prakṛti*, *kaniṣṭha-pada*, *hrasva-mūla*, or *ādya-mūla*; y is termed *jyeṣṭha-pada*, *jyeṣṭha-mūla*, or *anya-mūla*; and c is termed *kṣepa*, *prakṣepa*, or *prakṣepaka*. Brahmagupta's formulation of the equation as indicated in the first line of his well-known lemma and as explained by Pṛthūdakasvāmin, Sudhākara, and others says that 'an optional number (c) added to or subtracted from the product of the square of a number (x^2), and an optional multiplier (N) yields a square root (y^2)'.[32] In clear terms Bhāskara II in his *Bījagaṇita* (*Varga-prakṛti*, 1) defines the equation as follows: 'The square of the optional lesser number (*iṣṭa hrasva*) multiplied by the *prakṛti* and increased or decreased by the positive or negative interpolator (*kṣepaka*) gives a square root called the greater root (*jyeṣṭha-mūla*)', that is,

$$Nx^2 \pm c = y^2.$$

The method adopted by Brahmagupta and other early mathematicians was to find a first set of integral values of x and y and form the auxiliary equation

$$N^2 \pm 1 = B^2.$$

From these an unlimited number of integral solutions can be readily obtained by the lemma of Brahmagupta which was applied by Bhāskara II and later mathematicians. By this method one can obtain an infinite number of solutions as stated in the rule itself. In Europe, Fermat (*c.* A.D. 1640) was once believed to have been the first to state that an indeterminate equation of the second degree of the type discussed above has an unlimited number of integral solutions.[33] The equation with interpolator was mistakenly called the Pellian equation after John Pell (A.D. 1668), a younger contemporary of Fermat. In India such equations and full methods of solving them appeared more than a thousand years before they did in Europe.

[31] H. Hankel, *Zur Geschichte der Math in Altertum und Mittelalter* (Leipzig, 1874), pp. 203-4.
[32] *Brāhmasphuṭa-siddhānta*, XVIII. 64.
[33] Smith, *op. cit.*, p. 453.

Cakravāla or the Cyclic Method: We have stated that in order to solve the indeterminate equation of the second degree of the type discussed, it is necessary to form an auxiliary equation in positive integers of *a*, *b*, and *c*. Brahmagupta did it by trial and error method for values of $c = \pm 1, \pm 2$, and ± 4. Bhāskara II gave solutions of the problem by a method he termed *cakravāla*.[34] The method seeks to derive from the equation $Na^2+c=b^2$ the following equation:

$$N\left(\frac{am+b}{c}\right)^2 + \frac{m^2-N}{} = \left(\frac{bm+Na}{c}\right)^2.$$

Here m is the multiplier so that m^2-N is the smallest. This multiplier is determined by the method of pulverizer (*kuṭṭaka*), of which the quotient $\frac{am+b}{c}$ is the lesser root. Note how the pulverizer is formed by taking the lesser root a as the dividend, the greater root b as the additive quantity, and the interpolator c as the divisor.

Recently, Clas-Olof Selenius of the University of Uppsala re-examined the Hindu *cakravāla* method and concluded that the method could be best explained in terms of the special new type of half-regular continued fractions.[35] Unlike the regular continued fractions used by Euler and Lagrange in explaining the Pell equation, the half-regular continued fractions are of a more general type and render numerical work maximally economical. The Hindu method, therefore, envisages a clear appreciation of deep-seated mathematical properties of continued fractions and of the theory of numbers. Selenius observes that the *cakravāla* method 'anticipated the European methods by more than a thousand years and surpassed all other Oriental performances.... The cyclic method is the absolute climax of the Indian mathematics in historical time and thereby also of all Oriental mathematics. In my opinion, no European performance at the time of Bhāskara, nor much later, came up to this marvellous height of mathematical complexity.'

Permutations and Combinations, Pascal Triangle, and Anticipation of Binomial Theorem: In the early Jaina canonical literature, permutation was termed *vikalpa-gaṇita* and combination, *bhaṅga*. Later on the term *chandaściti* was adopted to signify permutations and combinations. The rules had wide applications which Bhāskara II enumerated as follows: 'It serves in prosody, for those versed therein, to find the variations of metre; in the arts (as in architecture)

[34]For the rationale of the rule, see P. C. Sen Gupta, 'Origin of the Indian Cyclic Method for the Solution: $Nx^2+1=y^2$', *BCMS*, Vol. X (1918-19), pp. 73-80.

[35]Clas-Olof Selenius, 'Kettenbruchtheoretische Erklärung der zyklischen Methode zur Lösung der Bhaskara-Pell-Gleichung', *Acta Academiae Aboensis Mathematica et Physica*, XXIII, 10 (1963), pp.1-44; 'The Old Indian Methods for Solving Equations of the Second Degree', The Thirteenth International Congress of the History of Science, Moscow, *Proceedings*, Section V, pp. 202-6; 'Rationale of the Chakravāla Process of Jayadeva and Bhāskara II', *Historica Mathematica*, Vol. II (1975), pp. 167-84.

to compute the changes upon apertures (of a building); and (in music) the scheme of musical permutations; in medicine, the combinations of different savours. For fear of prolixity, this is not (fully) set forth.'[36]

The *Suśruta-saṁhitā* (LXIII.1-9) correctly gives the sum of combinations of six tastes taken one at a time, two at a time, etc. up to all at a time. The Jaina *Bhagavatī-sūtra* calculates the number of combinations of n fundamental categories taken one at a time, two at a time, and so on. Varāhamihira has stated that 'an immense number of perfumes can be made from sixteen substances taken in one, two, three, or four proportions', and has correctly given the number of perfumes resulting from sixteen ingredients mixed in all proportions as 174,720.[37] The results given in all cases indicate the use of formulas whose modern forms are:

$$^{n}c_{r} = \frac{n(n-1)(n-2)\ldots\ldots\ldots\ldots(n-r+1)}{1.2.3\ldots\ldots\ldots\ldots\ldots r}$$

$$^{n}p_{r} = n(n-1)\ldots\ldots\ldots\ldots\ldots\ldots(n-r+1).$$

Varāhamihira in his astrological work, the *Bṛhajjātaka*, applied the same principle in connection with planetary conjunctions.

An interesting rule for finding the number of combinations of n syllables taking 1, 2, 3, etc. up to n at a time has been given in Piṅgala's *Chandaḥ-sūtra* and is known as *meru-prastāra*. It is the same as what came to be called Pascal's triangle in Europe in the seventeenth century[38] or *Ku fa chhi chhêng fang thu* in China in the fourteenth century.[39] Although named after Pascal owing to its full discussion in his *Traité du Triangle Arithmétique* published posthumously in A.D. 1665, it had already appeared in Europe on the title page of the arithmetic of Apianus (A.D. 1527) and had been discussed by other sixteenth-century European mathematicians such as Stifel (A.D. 1544), Scheubel (A.D. 1545), Tartaglia (A.D. 1556), and Bombelli (A.D. 1572). The method is that the binomial coefficients $n_{c_0}, n_{c_1}, n_{c_2} \ldots\ldots\ldots n_{c_n}$ for $n=0, 1, 2, 3, \ldots, n$ can be arranged in a triangular array so that any number in a row equals the sum of the two numbers immediately above.

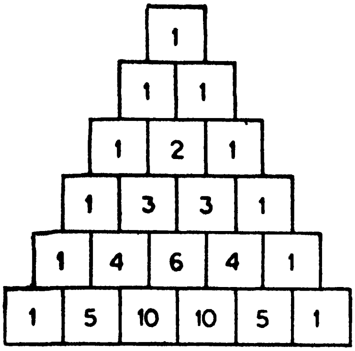
The method given in a cryptic form in the *Chandaḥ-sūtra* has been explained

[36] *Līlāvatī*, trans. Colebrooke, edited with notes by H. C. Banerjee (Calcutta, 1927), p. 71.

[37] *Bṛhat-saṁhitā*, LXXVII.13, 14, and 17. For further exposition see rules 18 to 21.

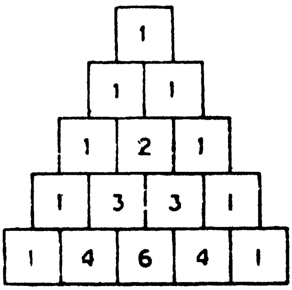
[38] Smith, *op. cit.*, p. 508.

[39] Needham, *op. cit.*, p. 134. This is given in Chu Shih-Chieh's *SSu Yuan Yü Chien* (A.D. 1303), but the method is believed to have been understood by the beginning of the twelfth century A.D.



$$\begin{array}{c} {}^{0}c_{0} \\ {}^{1}c_{0}\ \ {}^{1}c_{1} \\ {}^{2}c_{0}\ \ {}^{2}c_{1}\ \ {}^{2}c_{2} \\ {}^{3}c_{0}\ \ {}^{3}c_{1}\ \ {}^{3}c_{2}\ \ {}^{3}c_{3} \\ {}^{4}c_{0}\ \ {}^{4}c_{1}\ \ {}^{4}c_{2}\ \ {}^{4}c_{3}\ \ {}^{4}c_{4} \\ {}^{5}c_{0}\ \ {}^{5}c_{1}\ \ {}^{5}c_{2}\ \ {}^{5}c_{3}\ \ {}^{5}c_{4}\ \ {}^{5}c_{5} \end{array}$$

by the commentator Halāyudha (tenth century A.D.). The explanation given by him very clearly lends itself to the foregoing schematic representation.



$$\begin{array}{lr} 1(a)+1(b) & (a+b)^1 \\ 1(a^2)+2(ab)+1(b^2) & (a+b)^2 \\ 1(a^3)+3(a^2b)+3(ab^2)+1(b^3) & (a+b)^3 \\ 1(a^4)+4(a^3b)+6(a^2b^2)+4(ab^3)+1(b^4) & (a+b)^4 \end{array}$$

It is important to note that the *meru-prastāra* method is set forth in connection with the problem of determining the number of combinations of a given number of syllables in which the short or the long sound in a *pada* with all the syllables may occur once, twice, etc. up to the time of the total number of syllables. In the above exposition, a and b represent the short and the long sound, and 1, 2, 3, etc. the number of syllables. For example, in the case of a metre with four syllables, a *pada* may contain all the four short sounds (a^4), three short sounds and one long (a^3b), two short and two long sounds (a^2b^2), one short and three long sounds (ab^3), or all the four long sounds (b^4).

The *meru-prastāra* may be said to have anticipated the binomial theorem in finding the values of nc_0, nc_1, nc_2,$\ldots nc_n$ through the relation

$$n_{c_r} + n_{c_{r+1}} = n+1_{c_{r+1}}.$$

It is seen that the coefficients of the binomial expression $(a+b)^n$ can be readily determined by this process.[40] Thus it is incorrect to say that *meru-prastāra* 'has

[40]For a fuller account of the *meru-prastāra* method in its relation to the science of prosody in Sanskrit literature, see A. K. Bag, 'Binomial Theorem in Ancient India', *Indian Journal of History of Science*, Vol. I, No. 1 (1966), pp. 68-74.

nothing to do with binomial coefficients'.[41] Pascal's triangle with its full implication for the expansion of a binomial power (positive integral) series appears in India from the time of the *Chandaḥ-sūtra*, several centuries before any such knowledge is traceable in China. There is, therefore, no reason to suppose that Umar al-khayyami, whose mathematical works bear evidence of Indian influence, got the idea from some Chinese source.

GEOMETRY

Like other branches of mathematics, geometry in India in the post-Vedic period was developed in the course of dealing with practical problems. Although there are quite a few examples of important results having been obtained, the subject never grew into an abstract and generalized science in the manner it did at the hands of the contemporary Greeks. Problems receiving geometrical treatment were discussed under such topics as *kṣetra* (plane figures), *khāta* (excavations or cubic figures), *citi* (piles of bricks), *krakaca* (saw problems or cubic figures), and *chāyā* (shadows dealing with problems of similarities and proportions). This mode of treatment continued up to the time of Bhāskara II or even later. Elements of Greek geometry gradually filtered into Sanskrit treatises mainly through Arabic and Persian works popular among Muslim circles in medieval India. Kamalākara's works bear witness to such influx. But it was not until the beginning of the eighteenth century that Euclid's *Elements* was translated into Sanskrit by Jagannātha (b. A.D. 1652) under the title of the *Rekhāgaṇita*. We shall here briefly discuss some typical geometrical problems which usually interested Indian mathematicians of the ancient and medieval periods.

Solution of right-angled triangles: The solution of right-angled triangles, whose sides a, b, c are connected by the relation $a^2+b^2=c^2$, constituted a favourite preoccupation of the Indians. Āryabhaṭa I made a general statement of the theorem. Brahmagupta gave general solutions of such triangles, whose sides can be given in rational numbers in the following form:

$$a=2mn;\ b=m^2-n^2;\ c=m^2+n^2,$$

where m and n are unequal rational numbers. Other exercises in rational triangles comprised the construction of right-angled triangles with rational sides when a side a or b was given. The *Brāhmasphuṭa-siddhānta* (XII.13) gives the solution as

$$a,\ \tfrac{1}{2}\left(\frac{a^2}{p}-p\right),\ \tfrac{1}{2}\left(\frac{a^2}{p}+p\right),$$

[41]Needham, *op. cit.*, p. 137, n. *a*.

where p is any rational number. Mahāvīra and Bhāskara II gave their solutions as

$$a, \frac{2na}{1}, \frac{(n^2+1)\,a}{n^2-1}.$$

The above solutions are simple transformations of Brahmagupta's results. In Europe these results are usually credited to Fibinacci and Vieta, but several centuries before them these results were known to Indian mathematicians.

Area of a quadrilateral: The *Brāhmasphuṭa-siddhānta* (XII.36) gives the area of a quadrilateral in the following terms: 'Half the sum of the sides is set down four times and (each time) lessened by the sides; the square root of the product is the exact area.' In other words, the

$$\text{area} = \sqrt{(s-a)\,(s-b)\,(s-c)\,(s-d)},$$

where a, b, c, and d are the sides and $s = \frac{1}{2}\,(a+b+c+d)$. The result is true for inscribed quadrilateral only, although Brahmagupta does not say so explicitly. Heron (*c*. A.D. 200) of Alexandria had given this formula a few centuries before it appeared in Indian works.

In the *Brāhmasphuṭa-siddhānta* we come across another remarkable formula giving correctly the diagonals of a cyclic quadrilateral, d_1 and d_2, as follows, where a, b, c, and d are the sides:

$$d_1 = \sqrt{\frac{(bd+ac)\,(ab+cd)}{ad+bc}}$$

$$\overline{\frac{(bd+ac)\,(ad+bc)}{ab+cd}}$$

These relations were given by W. Snell at the beginning of the seventeenth century in Europe.

TRIGONOMETRY

Trigonometry was developed as an integral part of astronomy. Without its evolution many of the astronomical calculations would not have been possible. Three functions, namely, *jyā*, *kojyā* (also *koṭijyā*), and *utkramajyā*, were used and defined as follows:

jyā	$AP = R\sin\theta,$
kojyā	$AP = R\cos\theta,$
utkramajyā	$AP = R - R\cos\theta = R\ \text{versin}\ \theta,$

where AP is the arc, R the radius, and θ the angle subtended by the arc at

the centre. From these definitions a number of elementary formulas were developed, of which a few are shown below:

$$\sin (90-\theta)=\cos \theta$$

$$\sin^2\theta = \frac{\sin^2 2\theta}{4} + \frac{\text{versin}^2 2\theta}{4}$$

$$\sin \left(\frac{\pi}{4} \pm \frac{\theta}{2}\right) = \sqrt{\frac{1 \pm \sin\theta}{2}}$$

$$\sin (A \pm B) = \sin A \cos B \pm \cos A \sin B$$

$$\sin 2\theta = 2 \sin\theta \cos\theta.$$

Fairly accurate sine tables were worked out and given in most astronomical texts to facilitate ready calculations of astronomical elements. The usual practice was to give the values at intervals of 3°45′, although other intervals also were sometimes chosen. Intermediate values were calculated by extrapolation. Brahmagupta, Bhāskara I, and others gave formulas for the direct calculation of the sine of any angle without consulting any table. Credit is due to the Indian mathematicians of the medieval period for the development of trigonometrical series and series of the following types:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\sin \theta = \theta - \frac{\theta^3}{4^3} + \frac{\theta^5}{4^5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\cos\theta = 1 - \frac{\theta^2}{4^2} + \frac{\theta^4}{4^4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\theta = \frac{\sin \theta}{\cos \theta} - \frac{1}{3}\left(\frac{\sin \theta}{\cos \theta}\right)^3 + \frac{1}{5}\left(\frac{\sin \theta}{\cos \theta}\right)^5 \quad \ldots\ldots\ldots\ldots\ldots (4)$$

These relations are found in four important mathematical-astronomical works, i.e. the *Karaṇapaddhati*, *Tantra-saṅgraha*, *Yuktibhāṣā*, and *Sadratnamālā*, all belonging to the period between the fifteenth and eighteenth centuries. The first and fourth series were rediscovered by Gregory in the seventeenth century, and the second and third by Newton. Thus in trigonometry there is evidence of an unbroken tradition of excellence and originality in India extending over several centuries.

CALCULUS

Rudimentary ideas of integration and differentiation are found in the works of Brahmagupta and Bhāskara II. Bhāskara II, in particular, determined the area and volume of a sphere by a method of summation analogous to integration. In the first method, the surface is divided into elementary annuli by drawing a series of parallel circles about any point on the surface. The number of such circles, according to Bhāskara II, can be as many as desired. The area of the sphere is given by the sum of areas of the annuli. To find the volume of the sphere, it is divided into a large number of pyramids with their bases lying on the surface of the sphere and their apices coinciding with the centre. The sum of the volumes of these pyramids gives the volume of the sphere.

In the definition of *tātkālikī gati* (instantaneous motion) by Bhāskara II and in his method of calculating its value, an elementary conception of differentiation is clearly indicated. The problem is presented in connection with the question of finding the instantaneous velocity of a planet. Earlier, he had given methods of determining the mean and true longitudes of any planet for any instant of time. The results he now gives for such instantaneous velocities indicate differentiation of the type: $d\,(\sin\theta)=\cos\theta\, d\,\theta$.

In conclusion, it may be stated that mathematics is a specialized discipline the knowledge of which must necessarily remain confined to only a few persons having an exceptional interest in the subject and its application. This was particularly the case until the advent of modern science and the expansion of education at higher levels. In India also during the ancient and medieval times the study of mathematics was the preoccupation of a few astronomers-cum-astrologers scattered all over the country. Nevertheless, the development of mathematics to the extent we have seen in the foregoing review must be attributed to something special in the intellectual efforts of the Indians of this period.

5

ASTRONOMY IN ANCIENT INDIA

THE Vedas prescribed various *yajñas* or sacrifices to be performed in different seasons of the year. The duration of these sacrifices used to vary; some were seasonal, some four-monthly, some year-long, and others even longer. It was necessary to calculate the time to begin and end a sacrifice. This presumably led the Vedic Indian to turn to astronomy. The winter and summer solstices formed the basis of their seasonal calculations. The ascertained solstice days almost always coincided with the full moon, new moon, or last quarter of the lunar month. The seasons were calculated beginning from the *uttarāyaṇa* —the winter solstice or the first day of the sun's northerly course. There were six seasons, each of two months: winter, spring, summer, rains, autumn, and dews.

Early researchers came across a Vedāṅga tradition about the position of the solstices of the Vedic period. It states that the sun turns north at the beginning of the Dhaniṣṭhā division and south at the middle of the Aśleṣā division —a phenomenon which is known to have prevailed during the period between 1400 and 1200 B.C. This led them to consider this period as the earliest phase of the Vedic age. Now, however, the positions of the solstices and equinoxes in the successive ages of the Vedic and post-Vedic times have been ascertained to be as follows:

1. The summer solstice at about β Leonis, the winter solstice at about α Pegasi,[1] and the vernal equinox near λ Orionis suggest a period of about 4000 B.C., although the Vedic statement gives the position of the winter solstice alone.[2]
2. The vernal equinox near α Tauri (Rohiṇī) and consequently the summer solstice at about δ Leonis indicate a period close to 3000 B.C.[3]
3. The vernal equinox at about η Tauri (Kṛttikās) and the summer solstice about α Leonis (Maghā) occurred around 2350 B.C.[4]
4. The summer solstice about the first point of the Maghā division and the winter solstice at the middle of the *nakṣatra* Dhaniṣṭhā suggest a period near about 1800 B.C.[5]

[1] P. C. Sen Gupta, *Ancient Indian Chronology* (University of Calcutta, 1947), pp. 68 and 79.
[2] *Atharva-Veda*, XIII.1.6; Sen Gupta, *op. cit.*, pp. 95ff.
[3] Sen Gupta, *op. cit.*, pp. 135, 151, 161, and 169.
[4] *Ibid.*, pp. 15-18, 32, 42, 172, and 174.
[5] *Ibid.*, pp. 192-93.

5. Lastly, the summer solstice at the middle of the Aśleṣā division and the winter solstice at the first point of the Dhaniṣṭhā division took place about 1400 B.C.[6]

The manner in which these positions were ascertained in the Vedic period may be determined from a passage in the *Aitareya Brāhmaṇa* (XVIII.18) which says or rather indicates that the sun remained stationary at the rising point or maintained the same meridian zenith distance for twenty-one days at the solstices.[7] The true solstice day was the middle of these twenty-one days—*madhya eṣa ekaviṁśa... iti*. The twenty-one days in which the sun remained stationary at the solstice were divided into ten, one, and ten days. The two periods of ten days at the beginning and at the end were styled *virāja*. Since at the end of the sun's northerly course the sun's rising point remained stationary for twenty-one days, it was thought that the middle or the eleventh day was the true summer solstice day. Similarly, the eleventh day of the solstice at the end of the sun's southerly course was the winter solstice day. When the solstice day fell on a new moon day, the new moon *nakṣatra* gave the position of the solstitial point. Likewise, when the solstice day fell on a full moon day, the moon's *nakṣatra* gave the position of the opposite solstitial point. The observation of the retardation in the moonrise after the full moon could exactly settle the full moon day and also perhaps the instant of the full moon. Similarly, the observation of the entire period of invisibility of the moon after the new moon led to the correct estimate of the exact day and perhaps of the hour of the instant of the new moon.

The observation of the phase of the moon on the solstice day settled the nature of the Vedic calendar, whether the lunar months were to be reckoned as ending with the full moon, the new moon, or even with the last quarter of the lunations. Sometimes after four years the months ending with the full moon and starting from the winter solstice day were changed into months ending with the new moon. In four years there are $365{\cdot}25 \times 4 = 1461$ days, and in 49·5 lunations there are $29{\cdot}53 \times 49{\cdot}5 = 1461{\cdot}75$ days nearly. Hence in the observational methods forming the Vedic calendar, this procedure of changing the system of reckoning lunar months from months ending with the full moon to those ending with the new moon and *vice versa* was quite possible. In the *Mahābhārata* we have a record of such a procedure.

Again, in six years there occur 2191·5 days comprising 74 lunations plus 6·25 days nearly. A winter solstice on a full moon day in the month of Māgha (January-February) will in six years fall on the seventh day of the dark half of the month, and the first day of the sun's northerly course will fall on the next day, i.e. the day of the last quarter. This idea is supported by the statement

[6] *Ibid.*, pp. 189-91.
[7] *Ibid.*, pp. 155-58.

vyaṣṭakāyām uttaram (the first day of the next year will fall on the day of the last quarter) in the *Taittirīya Brāhmaṇa.*

In those days the lunar phase of the solstice day gave the mode of reckoning the coming lunar months. In ordinary calendars it was generally preferred to follow the lunar months ending with either the new moon or the full moon. Sometimes there arose a special necessity for finding the winter solstice day of a particular year, which led to the determination of the new phase of the moon for finding the first day of the new year. This settled the dates for beginning the Vedic sacrifices lasting two or four lunations. Among the sacrifices the *jyotiṣṭoma* and *vājapeya* — the spring and the summer sacrifice respectively — were of two months' duration each. The four-monthly (*cāturmāsya*) sacrifices lasted the four months of spring and summer. For these, both the solstice days were very frequently determined in the process mentioned above. The *Aitareya Brāhmaṇa*, however, speaks of only the summer solstice day. The year-long sacrifices, like the *aśvamedha* and *rājasūya,* began from the spring and lasted twelve lunations. The beginning of spring was taken at 60 or 61 days after the winter solstice day,[8] which was a fair approximation.

The long-period sacrifices performed by the Vedic people sometimes extended to three, five, or twelve years. In three years there was evidently one additive lunar month,[9] while in five years there were two.[10] Thus in eight years three additive months had to be reckoned with. Consequently in four years there were one and a half additive months and in twelve years four and a half additive months.[11] The Śrautasūtras also speak of sacrifices which lasted for thirty-six years or even longer periods.

The Vedic people were keen observers of the motions of the moon amongst the fixed stars. The ecliptic stars were regarded as so many milestones for the moon's motion in a sidereal month. The stars and star clusters about the ecliptic were probably named and reckoned as twenty-seven or twenty-eight, the period of revolution of the moon being between twenty-seven and twenty-eight days. In the *Mahābhārata* (III.230.10) the *nakṣatras* are stated to be twenty-seven in number when Rohiṇī (Aldebaran) is the first star, a phenomenon which may be dated at about 3000 B.C. Many are the *nakṣatras* mentioned in the *Ṛg-Veda,* but we cannot be definite whether all the twenty-seven or twenty-eight *nakṣatras* were recognized before the time of the *Taittirīya Saṁhitā* (*c.* 2446 B.C.). Of the twelve signs of the zodiac, the *Ṛg-Veda* (I.57.1) refers to Meṣa (Aries) and Vṛṣabha (Taurus). But it may be doubted if such references really point to anything similar to the signs of the zodiac as conceived by the ancient

[8] *Kauṣītaki Brāhmaṇa,* XIX.3.
[9] *Kātyāyana Śrautasūtra,* XXIV.168.
[10] *Baudhāyana Śrautasūtra,* XVIII.11.
[11] *Kātyāyana Śrautasūtra,* XXIV.175.

Babylonians and Greeks. The twelve signs of the zodiac do not figure in the whole of the Sanskrit literature prior to A.D. 400. In the *Mahābhārata* there is no mention of the signs of the zodiac. Neither are the days of the week mentioned in the *Mahābhārata* or the Vedas. Each day of the lunar month was named after the star or constellation with which the moon was conjoined on that particular day.

In the *Aitareya* and *Kauṣītaki Brāhmaṇas* we have a detailed description of the *gavāmayana* sacrifice. The rules of this sacrifice prescribed the sacrificial days of the year: 180 each for the northerly and southerly courses of the sun. The six extra (*atirātra*) days were not regarded suitable for ordinary sacrifices. These *atirātra* days were distributed through the year at different intervals, resulting in varying calculations of the lengths of the sun's northerly and southerly courses during the Vedic period as shown in the following table:

Year B.C.	*Northerly course*	*Southerly course*
4000	187 days	178·24 days
3000	186·75 days	178·49 days
2000	186·10 days	179·14 days
1000	185·20 days	180·04 days

Both the summer and winter solstice days could probably be determined in the earliest phase of the Vedic period. In the later phase, however, only the winter solstice day used to be determined. Although the term *gavāmayana* means 'motion of rays', it really implies the two courses of the sun's apparent motion. These courses are of equal duration when the sun's apogee or perigee coincides with either the summer or the winter solstitial point. The approximate date on which such a conjunction might have taken place is A.D. 1266.

VEDIC ANTIQUITY[13]

The earliest date in Vedic antiquity has been determined astronomically to be about 4000 B.C. This same antiquity is suggested in the works of Jacobi and Tilak. Another view, based on the position of the *nakṣatra* Rohiṇī, places

[13]The dates relating to the Vedic period are controversial and have not found general acceptance by scholars. The chronology of Vedic literature has always been, and is even now, a matter of great difficulty. Considering that the whole of Vedic literature must be pre-Buddhist and the Sūtra works synchronous with the origin and spread of Buddhism, Max Müller suggested the period between 600 and 200 B.C. for the development of the Sūtras, the period between 800 and 600 B.C. for the development of the prose style of the Brāhmaṇas and Āraṇyakas-Upaniṣads, and the period 1000 to 800 B.C. for the compilation of the Saṁhitās, of which the poetry part or the *mantras* probably originated in the period between 1200 and 1000 B.C. In his view, the oldest of the Vedas, the *Ṛg-Veda*, could not have been composed earlier than 1200 B.C. Leopold von Schroeder suggested a much earlier date, 1500 or even 2000 B.C. for the *Ṛg-Veda*, while Hermann Jacobi and B. G. Tilak, on astronomical grounds, tried to date the beginning of Vedic literature in the third millennium B.C. The period around 1400 or 1500 B.C. for the formulation of the earliest Ṛg-Vedic hymns has

the beginning of the Vedic period at about 3000 B.C. Thirdly, on the basis of the position of the *nakṣatra* Kṛttikā and the summer solstice at Maghā, the Vedic age has been assigned to 2350 B.C. It was about this time that the *Ṛg-Veda* was supposed to have been completed. It was perhaps also the latest date referred to in the *Atharva-Veda.* The *Yajur-Veda* also possibly dates from this time. The remaining or the fourth Veda, the *Sāma,* dealing with melodies (*sāman*), presents no new features. Regarding Vedic ritual literature, it has been possible to fix the dates of the *Jaiminīya Brāhmaṇa* and the *Tāṇḍya* or *Pañcaviṁśa Brāhmaṇa* at about 1625 B.C., the *Śāṁkhāyana* (*Kauṣītaki*) *Brāhmaṇa* at about 1000 B.C., the *Baudhāyana Śrautasūtra* at about 900 B.C., the *Śatapatha* and *Taittirīya Brāhmaṇas* at about 756 B.C., and the *Kātyāyana* and *Āpastamba Śrautasūtras* at about 625 B.C.[13] Fourthly, the traditional position of the summer solstice at the middle of the Aśleṣā division and that of the winter solstice at the beginning of the Dhaniṣṭhā division probably led Max Müller to estimate the earliest limit of the Vedic antiquity to be about 1200 to 1000 B.C.

Winternitz placed the Vedic antiquity between 2500 and 2000 B.C. In this calculation he was probably guided by several statements in the *Yajur-Veda* which say that the Kṛttikās are at the head of the year. Neither Max Müller nor Winternitz could recognize the facts that Rohiṇī being the first star and the line of Parameśin (Brahmā) passing through Pūrvabhādrapada or α Pegasi indicated respectively the vernal equinox at about 3000 B.C. and the winter solstice at about 4000 B.C.

PROGRESS OF VEDIC ASTRONOMY

In Vedic astronomy the solar year was calculated as seasonal and hence tropical, but the lunar months were apparently sidereal, as the names of the months bear a purely sidereal character. The Vedic tropical months linked with the seasons were as follows: Tapas and Tapasya (winter), Madhu and Mādhava (spring), Śukra and Śuci (summer), Nabhas and Nabhasya (rains), Iṣa and Ūrja (autumn), and Sahas and Sahasya (season of dews or Hemanta). The year was further divided into three seasons or *cāturmāsyas.* Spring and summer formed the dry *cāturmāsya,* the rains and autumn comprised the moist *cāturmāsya,* and Hemanta and winter constituted the winter *cāturmāsya.*

The relation of these solar months to the lunar sidereal months at different periods is shown in the following table:

found a strong support from the clay tablets discovered in Boghazköi, the capital of the ancient Hittites, who had as their deities some of the common Vedic gods such as Mitra, Varuṇa, Indra, and Nāsatyau. However, from an analysis of different studies of the Vedic chronology Winternitz concluded, and this view is now generally followed, that 'we shall probably have to date the beginning of this development about 2000 or 2500 B.C. and the end of it between 750 and 500 B.C.'—Ed.

[13] Sen Gupta, *op. cit.*, pp. xviii-xx.

Season	*Tropical Solar Months*	*Lunar Months*		
		4000 B.C.	3000 B.C.	1400 B.C.
Winter	Tapas	Caitra	Phālguna	Māgha
	Tapasya	Vaiśākha	Caitra	Phālguna
Spring	Madhu	Jyaiṣṭha	Vaiśākha	Caitra
	Mādhava	Āṣāḍha	Jyaiṣṭha	Vaiśākha
Summer	Śukra	Śrāvaṇa	Āṣāḍha	Jyaiṣṭha
	Śuci	Bhādra	Śrāvaṇa	Āṣāḍha
Rains	Nabhas	Āśvina	Bhādra	Śrāvaṇa
	Nabhasya	Kārttika	Āśvina	Bhādra
Autumn	Īṣa	Mārga	Kārttika	Āśvina
	Ūrja	Pauṣa	Mārga	Kārttika
Hemanta	Sahas	Māgha	Pauṣa	Mārga
	Sahasya	Phālguna	Māgha	Pauṣa

The lunar months ended with either the full moon or the new moon, as the character of the months changed with the fresh determination of the solstice days of either description at the end of every four years. About 3000 B.C. a lunar month of Māgha was found to have the following distinctive characteristics: it began with the new moon at the Dhaniṣṭhā (Delphinis) cluster; the full moon was at the star Maghā (Regulus); and the last quarter was conjoined with the star Jyeṣṭhā (Antares). In successive ages the winter solstice days were stated with reference to several phases of this month of Māgha. These phases according to the *Taittirīya Saṁhitā* were: the day of *ekāṣṭakā*, which was true at about 2934 B.C.;[14] the day of the full moon at Phalgu, which occurred about 3500 B.C.; and the day preceding the full moon of Māgha, which was valid for 2446 B.C. In the Vedāṅgas (1400 B.C.) the winter solstice day is stated to have been on the new moon day of the standard month of Māgha.

In later times this standard month of Māgha ended with the full moon of Māgha conjoined with the *nakṣatra* Maghā (Regulus). The length of the year, though tropical, was considered to be 366 days. Similarly, the number of *nakṣatras* was held to be twenty-eight, as the moon's sidereal period exceeded twenty-seven days. Prior to the *Āryabhaṭīya* (*c.*A.D. 499) the mean measure of a *nakṣatra* was taken as 13 deg. 10 min. 35 sec., which is equal to the moon's mean daily motion. Six such *nakṣatras*, namely, Viśākhā, Punarvasu, Rohiṇī,

[14] *Ibid.*, p. 169.

Uttaraphālgunī, Uttarāṣāḍhā, and Uttarabhādrapada, had each a measure of 19 deg. 45 min. 52 sec., which is equal to one and a half mean measure. Six others, namely, Aśleṣā, Ārdrā, Svātī, Bharaṇī, Jyeṣṭhā, and Śatabhiṣā, had each a measure of 6 deg. 35 min. 57 sec., which is half a mean measure. Fifteen more *nakṣatras* had each a measure of 13 deg. 10 min. 35 sec., which is the mean measure. Abhijit, the twenty-eighth *nakṣatra*, was assigned a measure of 4 deg. 14 min. 18 sec.[15] From the foregoing calculations we find that the six *nakṣatras*, each of one and a half mean measure, accounted for the moon's nine daily motions; the six *nakṣatras*, each of half a mean measure, accounted for the moon's three daily motions; the fifteen *nakṣatras*, each of one mean measure, accounted for the moon's fifteen daily motions; and Abhijit accounted for the moon's motion in 7·6185 hours. Hence the moon's mean period of revolution comes to 27 days 7·6185 hours.

There is evidence that the winter solstice day with the lunar phase of the lunation was determined very frequently in the Vedic period. However, no record of these determinations has survived, from which a really accurate luni-solar astronomy could be evolved. But it is known that in a quinquennium or five-year cycle there were sixty-two lunations and sixty-seven revolutions of the moon and that the year was considered as consisting of 366 days.

In the later Vedic period, only the winter solstice days were determined. But the fact that the sun's northerly and southerly courses were never of equal length does not figure in the Brāhmaṇas. This is borne out by the *Yājuṣa-jyotiṣa* (verse 9) which gives the ten *tithis* or lunar days[16] for the first days of the sun's ten courses (i.e. five northerly and five southerly) in a quinquennium as: 1, 7, 13, 4, 10; 1, 7, 13, 4, 10 — the even numbers representing the *tithis* of the dark halves of the months. The year was assumed to be equal to twelve lunations plus twelve *tithis*. The rules for the first lunar *nakṣatras* of the ten courses of the quinquennium were based on similar rules and were determined as follows. In a quinquennium there were sixty-seven revolutions of the moon, each having twenty-seven *nakṣatras* into which the whole circle was divided. The *nakṣatra* durations in the five-year long luni-solar cycle thus came to 1809, each of the ten courses of the sun being equal to the moon's passage through 180·9 *nakṣatra* durations, which comprise six revolutions of the moon or the moon's transit through 18·9 *nakṣatras*. Hence the first lunar *nakṣatras* of these ten courses are stated as: Dhaniṣṭhā, Citrā, Ārdrā, Pūrvabhādrapada, Anurādhā, Aśleṣā, Aśvinī, Pūrvāṣāḍhā, Uttaraphālgunī, and Rohiṇī.[17] This system of reckoning started around 1400 B.C. and continued till about the beginning of the period of the Siddhāntas. Care was possibly taken to start

[15] See *Siddhānta-śiromaṇi*, *Grahagaṇita*, 2.71-75; *Brāhmasphuṭa-siddhānta*, XIV.46-52.
[16] A *tithi* is a period in which the moon gains 12° over the sun, or 1/30 of a lunation.
[17] *Yājuṣa-jyotiṣa*, verse 10.

the quinquennium from the day when the sun, moon, and Dhaniṣṭhā rose simultaneously above the horizon. In the luni-solar reckoning there was no idea of the moon's nodes or of the apogees of the sun and moon. During the period between 1400 B.C. and the age of the Siddhāntas twenty-eight unequal *nakṣatras* were accepted, which was a decided improvement on the idea of equal *nakṣatras* of the Vedāṅga period.

Time indications which are based on astronomical phenomena like heliacal risings of the stars, the solstice day of either description in terms of the lunar phase of a lunar month, the positions of the solstices, and even the equinoctial positions are available in ancient Indian treatises. In the *Tāṇḍya* and *Jaiminīya Brāhmaṇas* the only time indication is found to be the winter solstice day falling on the day of the heliacal visibility of the Delphinis cluster, which has led to their antiquity being set around 1625 B.C. As to the *Śāṁkhāyana* or *Kauṣītaki Brāhmaṇa*, three of the above four classes point to their approximate date being 1000 B.C. The *Baudhāyana Śrautasūtra* mentions three classes of time indications which suggest its date to be about 900 B.C. There is some evidence that the spring began on the full moon day of Phālguna and the summer solstice day fell on the full moon day of Āṣāḍha. From this, the date of these Brāhmaṇas is inferred to be about 750 B.C. The *Kātyāyana* and *Āpastamba Śrautasūtras* have not only time indications similar to those of the *Śatapatha* and *Taittirīya Brāhmaṇas*, but also additional indications which suggest their dates to be about 630 to 624 B.C.

In the *Sūrya-prajñapti*, a Jaina astronomical treatise, it is said that the sun turns south at the full moon near Abhijit, which indicates a date of about 600 B.C. In this work the astronomical methods and constants are identical with those of the *Vedāṅga-jyotiṣa*. We find in this work the theory of a flat earth, with the sun, moon, and stars moving in circles round the pole of the earth. Four mountain ranges were assumed as emanating from the pole and as being at right angles to each other. A curious feature of the astronomy of this period is that the distance from the earth to the moon was supposed to be twice the distance between the earth and the sun.

POST-VEDIC ASTRONOMY

In this section we propose to discuss the development of Indian astronomy from A.D. 100 to 500. According to tradition, Vṛddha Garga was the earliest Indian astronomer. His name is found in the *Mahābhārata* (IX.37.14-17; XII.59.111). When the *Mahābhārata* in its present form was compiled (*c.* fourth century A.D.), Vṛddha Garga had already come to be regarded as a great Indian astronomer who had lived many centuries earlier. The *Vṛddha Garga-saṁhitā* as we have it now, however, cannot be dated earlier than the second century A.D. Another astronomer was Lagadha, author of the *Yājuṣa-jyotiṣa*,

who discovered that the summer solstice passed through the middle of the *nakṣatra* Aśleṣā and the winter solstice through the first point of the *nakṣatra* Dhaniṣṭhā. He was followed by Garga and Parāśara who carried on his tradition as regards the solstices. We learn from Bhaṭṭotpala's commentary on the *Bṛhat-saṁhitā* (III.4) that in Garga's time the sun turned north before reaching the *nakṣatra* Dhaniṣṭhā and in Parāśara's time before reaching the *nakṣatra* Śravaṇā. It is thus clear that Garga lived after Lagadha, and Parāśara after Garga. Parāśara lived very probably in the third century A.D. Among other astronomers mentioned in Bhaṭṭotpala's commentary are Ṛṣiputra, Kapilācārya, Kāśyapa, and Devala. But there are no indications as to when they lived or what they achieved in the field of astronomy.

Varāhamihira's (*c.*A.D. 550) *Pañca-siddhāntikā* is the only available work to throw light on the development of astronomy during this period. In this work Varāhamihira summarizes the teachings of the *Pauliśa-*, *Romaka-*, *Vāśiṣṭha-*, and *Paitāmaha-siddhāntas*, and improves upon the *Sūrya-siddhānta* by incorporating the astronomical constants from the *ārdharātrika* system of Āryabhaṭa I. Varāhamihira states his opinion of the five *Siddhāntas* which he summarizes, thus: 'The *Siddhānta* made by Pauliśa is accurate; near to it stands the *Siddhānta* proclaimed by Romaka; more accurate is the *Sāvitra* (*Sūrya*); the two remaining ones are far from the truth.'[18]

The *Paitāmaha-siddhānta*, considered to be the most inaccurate of the five *Siddhāntas*, is described in the *Pañca-siddhāntikā* in five stanzas. The first one contains all the astronomical constants. According to the *Paitāmaha*, five years constitute a *yuga* of the sun and the moon. The *adhimāsas* are brought about by thirty months, and an omitted lunar day by sixty-two days. In five years there are sixty solar months; and hence, according to this rule, in five years there are two *adhimāsas* or additive lunar months. The number of lunar months is sixty-two; thus the number of *tithis* is 1860, which, when divided by sixty-two, gives the number of omitted lunar days as thirty. These are the same as in the *Vedāṅga-jyotiṣa*. The remaining four stanzas give rules for the use of these elements in calculating (a) the number of civil days elapsed from the light half of Māgha of 2 Śaka era, (b) the sun's *nakṣatra*, (c) the moon's *nakṣatra*, and (d) the number of *vyatīpātas* elapsed of the current *yuga*. It also notes that the shortest day was of twelve *muhūrtas* and the longest day of eighteen *muhūrtas*, and shows a rough method of finding the length of any given day in *muhūrtas*. The *Paitāmaha-siddhānta* does not treat of any other planets.

The *Vāśiṣṭha-siddhānta* (*c.* A.D. 300), the oldest of the five, is discussed in Chapters II and XVIII of the *Pañca-siddhāntikā*. From this discussion we deduce that the sidereal month was taken to consist of 27·32167063 days; that the length of the anomalistic month was considered to be 27·554 days; that the

[18] *Pañca-siddhāntikā*, I.4.

period of the moon's apogee was calculated as 3232·873219 days; and that the solar year was perhaps taken to consist of 365·366 days nearly. It is thus clear that considerable progress was made at the time in more correctly determining the luni-solar astronomical constants. The courses of the planets are treated in the following order: Venus, Jupiter, Saturn, Mars, and Mercury. These planetary courses relate to the direct motion, stationary stage (*anuvakra*), retrograde motion (*vakra*), and again the direct motion, and are given in the *Pañca-siddhāntikā* (XVIII.1-60). From the determination of these courses, the celestial longitudes of the planets could be calculated. The *Vāśiṣṭha-siddhānta* gives rough rules for finding the *lagna* or ecliptic point on the eastern horizon and furnishes the synodic periods in days of the five planets as follows: Venus, $584 - \frac{1}{11}$; Jupiter, $399 - \frac{1}{9}$; Saturn, $378 \cdot \frac{1}{11}$; Mars, $780 \cdot \frac{4}{45}$; and Mercury, 115 days 52 *nāḍikās* 45 *vināḍikās*.[19]

In using the signs of the zodiac in place of *nakṣatras*, the *Vāśiṣṭha-siddhānta* represents the oldest system of Babylonian astronomy as transmitted to India. It shows no improvement in its treatment of spherical astronomy. Chapter II of the *Pañca-siddhāntikā* states the rules for calculating the length of the day as follows: The shortest day is 26 *nāḍikās* 31 *palas* in length; from the shortest to the longest, the days are thought to increase by 3 *palas* every day. This rough rule is on a par with those given in the *Vedāṅga-jyotiṣa* and *Paitāmaha-siddhānta*. The other rules for finding the longitudes of the moon and sun and the shadow of the gnomon at midday are also inexact. No definite method for the calculation of eclipses occurs up to the time of the *Vāśiṣṭha-siddhānta*.

The *Pauliśa-siddhānta*, according to Varāhamihira, maintained that there are 43,831 days in 120 years. Thus the length of the year was taken to be 365·2583 days. The longitude of the sun's apogee was taken to be 80°. The mean measure of this periphery of the sun's epicycle was considered to be about 15°8′, which is near to that accepted by Ptolemy, viz. 15°. However, the faulty text of this *Siddhānta* prevents us from forming any idea of its views about the mean motion and the equations of the moon.

As regards the moon's other elements, the author of the *Pauliśa-siddhānta* knew of the same two convergents to the anomalistic month, viz. $\frac{248}{9}$ days and $\frac{3031}{110}$ days, as were known to the author of the *Vāśiṣṭha-siddhānta*. According to the *Pauliśa-siddhānta*, the sidereal period of the revolution of the nodes of the moon was 6794·6854 days. The moon's greatest latitude was 270′ or 4° 30′, as in all other *Siddhāntas*.

[19]In the sexagesimal division of the day, the sub-units are thus related: 1 day=60 *nāḍikās* or *daṇḍas*; 1 *nāḍikā*=60 *vināḍikās* or *palas*; 1 *muhūrta*=2 *nāḍikās*.

The courses of the planets Mars, Mercury, Jupiter, Venus, and Saturn as given in the *Pauliśa-siddhānta* are found in the latter portion of Chapter XVIII of the *Pañca-siddhāntikā*. The synodic periods of these planets are stated to be as follows:

Planet	*Synodic period in solar days*	*Synodic period in civil days*
Mars	$768\frac{3}{4}$	779·9787
Mercury	$\frac{3312}{29}$	115·875
Jupiter	$\frac{2752}{7}$	397·968
Venus	$575\frac{1}{2}$	583·9061
Saturn	$\frac{1118}{3}$	378·11

As regards spherical astronomy, this *Siddhānta* gives the correct method of finding the length of the day, which is expressed in the equation:

R sin (ascensional difference) $= R \tan \phi \tan \delta$, where ϕ is the latitude of the station and δ is the sun's declination.

Rough rules for the calculation of the eclipses first occur in this *Siddhānta*. The lunar ecliptic limit is stated to be 13° and the sum of the semi-diameter of the moon and the shadow is assumed to be 55′. The difference of their semi-diameters is 21′. Hence the semi-diameter of the moon is 17′ and that of the shadow 38′.

In the treatment of solar eclipses we find the parallax in longitude expressed in time, i.e. the time by which the observer's apparent instant of conjunction differs from the instant of the new moon, and given as $\frac{4R \sin \text{(sun's hour angle)}}{R}$ *ghaṭikās*, where one *ghaṭikā* $= \frac{1}{60}$ of a day and the horizontal parallax of any planet is supposed to be $\frac{1}{15}$ of its daily motion. This is also a very imprecise rule. The sum of the semi-diameters of the moon and the sun was assumed to be 35′. Hence the diameter of the sun was taken as 18′.

The foregoing is a fairly complete account of the *Pauliśa-siddhānta* as given in the *Pañca-siddhāntikā*. It does not hint at the epicyclic theory, but it shows distinct improvement on the *Vāsiṣṭha-siddhānta*. The *Pauliśa-siddhānta* seems to have drawn much of its material from the Greek or Babylonian system of astronomy.

The *Romaka-siddhānta* as summarized by Varāhamihira in his *Pañca-siddhāntikā* bears a foreign name and represents perhaps the sum total of Greek astronomy transmitted to India. According to Varāhamihira, the luni-solar *yuga* of the *Romaka-siddhānta* comprises 2,850 years in which there are 1,050 *adhimāsas* and 16,547 omitted lunar days. From this it is inferred that there are 1,040,953 civil days and 3,520 synodic months in 2,850 years. The year thus consists of exactly 365 days 14′ 48″, as accepted by Ptolemy. The length of the synodic month is equal to 29 days 31′ 50″5‴ 37^{iv}, which is 29·5305816 days. According to Ptolemy, the length of the synodic month is equal to 29 days 31′ 50″8‴20^{iv}. The *Romaka* synodic month agrees more closely with that of the *Āryabhaṭīya*, according to which its length is equal to 29·530582 days.

The length of the anomalistic month is expressed as $\frac{3031}{110}$ days, i.e. 27·554 days. The moon's motion in anomaly per day is equal to 13° 3′ 53″ 58‴ 55^{iv} 51^{v} 45^{vi}. According to Ptolemy it is 13° 3′ 53″ 56‴ 29^{iv} 38^{v} 38^{vi}. It is evident that in respect of the lengths of the synodic and anomalistic months the *Pauliśa-* and *Romaka-siddhāntas*, and the *Āryabhaṭīya* are very nearly in agreement. The longitude of the sun's apogee is stated in the *Romaka-siddhānta* to be 75°, but Ptolemy gives it as 65° 30′ and Āryabhaṭa I as 78°. For purposes of comparison, the following equations of the centres of the sun and moon for their anomalies at intervals of 15° as given in the *Romaka-siddhānta* and by Ptolemy are listed. As can be readily seen, the equations for the sun agree very closely, but this is not so for those for the moon.

Anomaly	15°	30°	45°	60°	75°	90°
Romaka						
Equation of centre						
Sun	34′42″	68′37″	98′39″	122′49″	137′5″	143′23″
Moon	1°14′	2°25′	3°27′	4°15′	4°44′	4°56′
Ptolemy						
Equation of centre						
Sun	35′	69′	97′30″	121′	136′	143′
Moon	1°11′	2°19′	3°19′30″	4°8′	4°49′30″	4°59′

In the *Romaka-siddhānta* the revolutions of the moon's nodes are stated to be 24 in 163,111 days. One revolution thus takes 6,796 days and 7 hours. This figure according to Ptolemy is about 6,796 days and 11 hours, while Āryabhaṭa puts it at 6,794·749511 days. The rule for parallax in longitude is the same as in the *Pauliśa-siddhānta*. The rule for parallax in latitude is expressed in the following equation:

$$\text{Parallax in latitude} = \frac{\text{Moon's daily motion}}{15} \times \frac{R \sin (\text{zenith distance of nonagesimal})}{R}.$$

Evidently the horizontal parallax of the moon is to be calculated as $\frac{1}{15}$ of the daily motion. The greatest latitude of the moon is taken in the *Romaka-siddhānta* to be 270′, as in all the *Siddhāntas*. According to Ptolemy, however, this is about 5° or 300′. The mean semi-diameters of the sun and the moon are recorded as 15′ and 17′ respectively, while Ptolemy states them to be 15′40″ and 17′40″.

The *Sūrya-siddhānta* as it has come down to us seems to have had a precursor with the same title belonging to the period *c.* A.D. 400. A summary of a work bearing this name appears in the *Pañca-siddhāntikā*. But it cannot be taken to represent the *Sūrya-siddhānta*. Since Varāhamihira's summary of the *Sūrya-siddhānta* does not give us the exact contents of the old text, it is necessary to try to find the oldest strata in the version that has come down to us. In the second chapter of this version there are two distinct planetary theories, of which the first is a crude one, the second being the regular epicyclic theory. The first few stanzas of this chapter are as follows:

'Forms of time, of invisible shape, stationed in the zodiac, called the conjunction (*śīghrocca*), apsis (*mandocca*), and the node (*pāta*), are the causes of the motion of the planets. The planets, attached to these beings (positions) by cords of air, are drawn away by them with the right and left hand, forward or backward, according to nearness, towards their own places. A wind, moreover, called provector (*pravaha*) impels them towards their apices (*ucca*); being drawn away backward and forward, they proceed by a varying motion. When the planets, drawn away by their apices, move forward in their orbit, the amount of motion so caused is called their excess (*dhana*); when they move backward, it is their deficiency (*ṛṇa*).'[20]

What has been stated above represents a system of astronomy which preceded the epicyclic one and is quite distinct from it. According to this system, the *ucca* is of two classes. The first, *mandocca* (apsis), in the case of the sun and the moon where the angular motion is slowest, means the apogee; and in the case of other planets it is the aphelion point of the orbit. The other type of *ucca* is *śīghrocca* (the apex of quick motion or the conjunction), which in the case of the superior planets coincides with the mean place of the sun, and in that of the inferior planets is an imaginary point moving round the earth with the same angular velocity as the angular velocity of the planet round the sun. Its direction from the earth is always parallel to the line joining the sun and the inferior planet.[21] *Pāta* means the ascending node of the orbit.

[20] *Sūrya-siddhānta*, II.1-5 (trans. Burgess, Calcutta University, 1935).
[21] *Ibid.*, I.29; XII.85-87.

The action of *mandoccas* on the mean position of the planets may be explained thus: Let *UPMNM'* (Fig. 5.1) be the circular orbit of the sun or the moon round

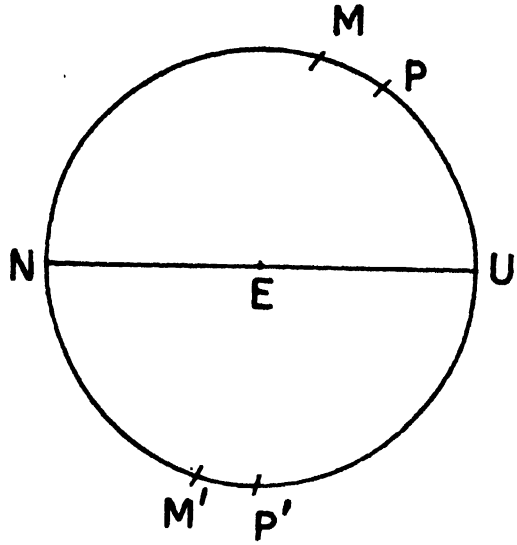


Fig. 5.1

the earth *E*; and let *U* be the position of the god of *mandocca* who is supposed to be sitting facing *E*, the earth. When the mean planet is anywhere at *M* in the half circle of *UMN*, it is drawn to a point *P* which is nearer to *U*. The pull, or rather the displacement, is *MP* and negative. Hence, according to this theory, the equation of the centre is negative from the apogee *U* to the perigee *N*. In the other half circle *NP'U*, the pull is exerted by the left hand, the mean planet *M'* is drawn forward to the point *P'*, and the equation of the centre is now positive. Thus so far as the character of the equation is concerned, this theory was deemed sufficient. The mean motion was thought to be produced by the planets being beaten by asterisms. The strings of air by which the god of apogee produced the displacements were given the name *pravaha*. It is further evident that the ideas of 'attraction' and the consequent 'displacement' were not fully distinguished. To sum up, this represents a system of astronomy which recognized only the inequalities due to apsis and tabulated the equations according to the position of the mean planet relative to the apogee. The other planetary inequality was considered to take place under the attraction of the god of *śīghra* or the quick apex. The older theory tells us that this god also draws the planet towards himself. This is separately illustrated for inferior and superior planets in the following paragraphs.

Śīghra of inferior planets: Let *E*, *H*, and *V* (Fig. 5.2) be the respective positions

of the earth, the sun, and an inferior planet in superior conjunction. From the line *EHO*, cut off *ES* equal to *HV*, the radius of the orbit of *V*; then *S* is the position of the *śighra* of *V*. After some days let *E′* and *V′* be the respective positions of the earth and the inferior planet. From *E′* draw *E′S′* equal and parallel to *HV′*; then *S′* is the new position of the *śighra*.

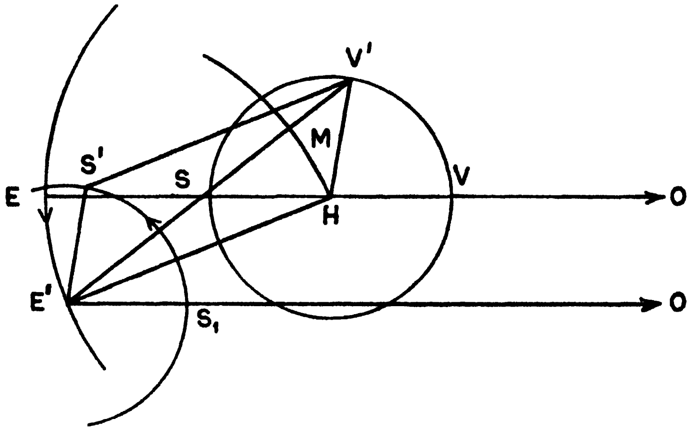


Fig. 5.2

The inferior planet is seen from *E′* in the direction *E′V′*. The *śighra* god has, as it were, drawn the mean inferior planet from the direction *E′H* to the direction *E′V′*, and the displacement produced is measured by the arc *HM* shown in the figure and is in the direction of *S′*; the line *E′H* is, as it were, turned towards *E′S′* to the position *E′V′*. In other positions of *E*, *V*, and *S* the displacements due to *śighra* are also readily explained.

Śighra of superior planets: Let *E*, *H*, and *J* (Fig. 5.3) be the respective positions of the earth, the sun, and a superior planet at conjunction. Let *E′* and *J′* be the positions in the respective orbits of the earth and superior planet after some days. The superior planet is now seen in the direction *E′J′* from *E′*. From *E′* draw *E′O* parallel to *EHJ*, and $E'J_1$ equal and parallel to *HJ′*. Here the *śighra* is *H*. The planet, instead of being seen in the direction $E'J_1$, is actually seen from *E′* in the direction *E′J′*. This displacement due to the *śighra H* is represented by the angle $J'E'J_1$ or the arc J_1M shown in the figure. The turning of the line $E'J_1$ into the position *E′J′* is towards *E′H* of the *śighra*. Similarly, in other positions of *E*, *H*, and *J*, the displacements due to *śighra* are readily explained in the diagram (Fig. 5.3).

It is evident that the imagined displacements due to this god of *śighra* are always towards himself and are sometimes positive and sometimes negative. This state of development of astronomy gives a picture of the older planetary

theory in the *Sūrya-siddhānta* regarding the presumed action of the gods of *manda* and *śīghra* on the motion of the planets. It is apparently pre-epicyclic. It shows that both the planetary inequalities were separated, howsoever imperfect this separation might have been.

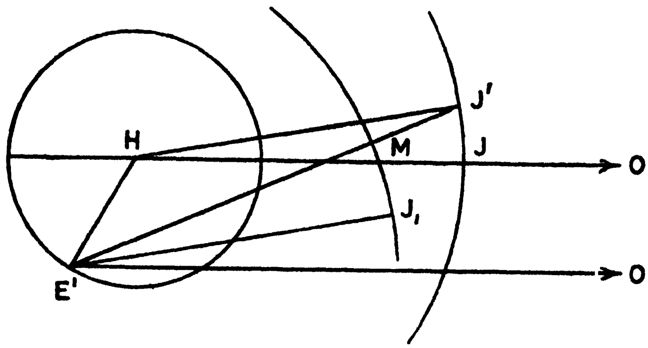


Fig. 5.3

The action of the *pātas* or ascending nodes on planetary movements is thus described in the *Sūrya-siddhānta* (II.6-8):

'In like manner, also, the node Rāhu by its proper (own?) force causes the deviation in latitude (*vikṣepa*) of the moon and the other planets, northward and southward, from their point of declination (*apakrama*). When in the half orbit behind the planet, the node causes it to deviate northward; when in the half orbit in front, it draws it away southward. In the case of Mercury and Venus, however, when the node is thus situated with regard to the conjunction (*śīghra*), these two planets are caused to deviate in latitude, in the manner stated, by the attraction exerted by the node upon the conjunction (*śīghra*).'

In the case of the inferior planets a very great advance was made when their celestial latitude was recognized as depending on the distance of the *śīghra* from the node. This step must have had a long history behind it which is now lost. The *Sūrya-siddhānta* (II.12-13) speaks of different kinds of planetary motions. As translated by Burgess, it says that 'the motion of the planets is of eight kinds, retrograde (*vakra*), somewhat retrograde (*anuvakra*), transverse (*kuṭila*), slow (*manda*), very slow (*mandatara*), even (*sama*), also very swift (*atiśīghra*) and that called swift (*śīghra*). Of these, the very swift, the swift, the slow, the very slow, and the even are forms of the motion called direct (*ṛju*); the somewhat retrograde is retrograde.'[22] These eight ways of planetary motion

[22]The concluding portion of the last stanza does not appear to have been properly translated by Burgess. The last sentence should have been: 'What are retrograde motions have been enumerated in proximity to *anuvakra* motion.' The last stanza means that the last five sorts of motion

may reasonably be considered as a relic of a forgotten history of Indian astronomy. These are referred to by Brahmagupta.[23] The *Pañca-siddhāntikā* (XVIII) while describing the course of planets (*grahacara*) speaks of the *vakra* and *anuvakra* motions, the latter motion taking place when the planet is reaching the next stationary point.

The planetary theory, according to the older strata of information found in the *Sūrya-siddhānta*, was based on records derived from observations with the help of which the positions of planets could be ascertained to a certain degree of approximation. It undoubtedly contained methods of calculating the eclipses and solving some problems in spherical astronomy, but we have no way of knowing what these methods were. The old *Sūrya-siddhānta* developed in India about A.D. 400 and very probably held its place of honour till A.D. 499 when Āryabhaṭa I began to teach the epicyclic astronomy.[24]

ĀRYABHAṬA I

Scientific Indian astronomy dates from the year A.D. 499 when Āryabhaṭa I of Kusumapura (Pāṭalīputra or Patna) began to teach astronomy to his pupils. Amongst his direct pupils, mention may be made of Pāṇḍuraṅgasvāmin, Lāṭadeva, and Niḥśaṅka. One Bhāskara, whom we shall refer to as Bhāskara I, was perhaps also a direct pupil of Āryabhaṭa I; or he might have been a pupil of his direct pupils. Bhāskara I was the author of the *Laghubhāskarīya* and the *Mahābhāskarīya* which treat of Āryabhaṭa's system of astronomy. He also wrote a commentary on the *Āryabhaṭīya*. He is mentioned by Pṛthūdaka in his commentary on the *Brāhmasphuṭa-siddhānta* (X.26) of Brahmagupta. Among the direct pupils of Āryabhaṭa I, Lāṭadeva, expounder of the old *Romaka-* and *Pauliśa-siddhāntas*, got the appellation of *sarva-siddhānta-guru*, i.e. teacher of all the systems of Siddhāntas. No mention of his pupils of lesser fame is found in any available works. Āryabhaṭa I was original in the construction of his new science. He was the author of two distinct systems of astronomy, the *audayika* and the *ārdharātrika*. In the first, the astronomical day begins at the mean sunrise at Laṅkā, and in the other, it begins at the mean midnight. The *Āryabhaṭīya* teaches the *audayika* system, and the *Khaṇḍakhādyaka* the *ārdharātrika* system. A comparison of the astronomical constants of the Greek

enumerated in the twelfth stanza are direct and the first three are retrograde. Burgess's observation on this is worth quoting. He says: 'This minute classification of the phases of a planet's motion is quite gratuitous so far as this *Siddhānta* is concerned, for the terms here given do not occur afterward in the text.' We think he could have also said that the conception of the gods of *manda* and *śighra* for explaining planetary inequalities was equally so.

[23] *Brāhmasphuṭa-siddhānta*, XI.9; see also the *Bṛhat-saṁhitā*, VIII.15-16 and Bhaṭṭotpala's commentary thereon.

[24] *Sūrya-siddhānta*, trans. E. Burgess. Introduction by P.C. Sen Gupta (Calcutta University, 1935), p. xxviii.

and the Indian systems points unmistakably to the conclusion that the Indian constants determined by Āryabhaṭa I and his successors are in almost all cases different from those of the Greeks. As regards doctrine, the material available at present makes it impossible to ascertain which part of it also belongs to the Indian astronomers.

Theory of Planetary Motions: Āryabhaṭa teaches his theory of planetary motions as follows: 'All planets move in eccentric orbits at the mean rates of angular motion, in the direction of the signs of the zodiac from their apogees (or aphelia) and in the opposite direction from their *śighroccas*. The eccentric circles of planets are equal to their concentrics, and the centre of the eccentric is removed from the centre of the earth. The distance between the centre of the earth and the centre of the eccentric is equal to the radius of the planet's epicycle; on the circumference (of either the epicycle or the eccentric) the planet undoubtedly moves with the mean motion.'[25]

(a) *Eccentric Circle Construction*: It was known that the planets move uniformly in circles round the earth. If the motion appeared to be variable, it was due to the fact that the centres of such circles (i.e. the eccentric circles) did not coincide with the centre of the earth. To illustrate the point, let E (Fig. 5.4) represent the centre of the earth and APM represent the sun's circular orbit or concentric; let A and P be the apogee and the perigee respectively. From EA, cut off EC equal to the radius of the sun's epicycle. With C as the centre and with the radius equal to EA, describe the eccentric $A'P'S$, cutting PA and PA produced at P' and A'. Here A' and P' are the real apogee and perigee of the sun's orbit. Let PM and $P'S$ be any two equal arcs measured from P and P'.

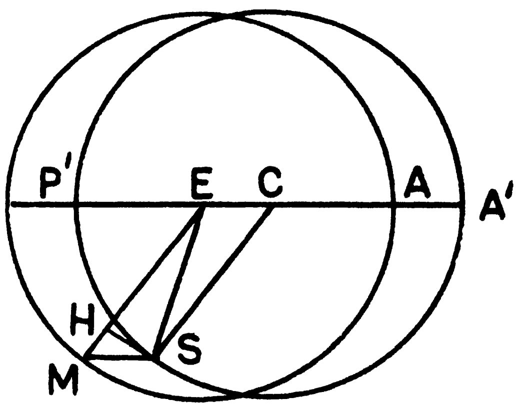


Fig. 5.4

[25] *Āryabhaṭīya*, *Kālakriyā*, 17-19; see also *Brāhmasphuṭa-siddhānta*, XIV. 10-12 and *Siddhānta-śiromaṇi*, *Golādhyāya*, 5.7.10-32.

The idea is that the mean planet M and the apparent sun S move simultaneously from P and P' in the counter-clockwise direction along the concentric and the eccentric circle respectively. They move with the same angular motion and arrive simultaneously at M and S. In the above figure EM and CS are parallel and equal, hence MS is equal and parallel to EC. Let SH be drawn perpendicular to EM. The angle PEM is the mean anomaly and the angle $P'ES$ the true anomaly; the angle SEM is the equation of the centre and is readily seen to be + from P' to A' and — from A' to P'. Thus as regards the character of the equation, the eccentric circle is quite right. We now turn to examine how far it is true as to the amount.

Let the angle SEM be denoted by E and the angle PEM=the angle $P'CS=\theta$.

$$EP=CP'=a;\ EC=MS=p;\ \text{then } \tan E = \frac{SH}{HE} = \frac{p\sin\theta}{a-p\cos\theta}$$

$$\therefore\ E = \frac{p}{a}\sin\theta + \frac{p^2}{2a^2}\sin 2\theta + \frac{p^3}{3a^3}\sin 3\theta + \dots$$

Now the true value of E in elliptic motion is given[26] by

$$E=\left(2e-\frac{e^3}{4}\right)\sin\theta + \frac{5}{4}e^2\sin 2\theta + \frac{13e^3}{12}\sin 3\theta + \dots$$

If we now put $\frac{p}{a}=2e-\frac{e^3}{4}$, as a first approximation $\frac{p}{a}=2e$.

Hence $\frac{p^2}{2a^2}=2e^2$, which is greater than $\frac{5}{4}e^2$ by $\frac{3}{4}e^2$.

In the case of the sun, if the value of p be correctly taken, the error in the co-efficient of the second term becomes $+3'$; similarly, in the case of the moon the corresponding error becomes $+8'$. Again, if $\frac{p}{a}=2e$, the centre of the eccentric circle is the empty focus of the ellipse; i.e. the ancient astronomers assumed the planets to be moving with uniform regular motion round the empty focus. This was not a bad approximation.

Also, $ES=r=EH$ approximately.

$$\therefore\ r=a\left(1-\frac{p}{a}\cos\theta\right).$$

But in elliptic motion[27]

$$r=a(1-e\cos\theta).$$

Hence the error is not very considerable here either. This is the way in which the ancient astronomers, both Greek and Indian, sought to explain the inequalities in the motion of the sun and the moon. In the case of the moon,

[26] H. Godfray, *A Treatise on Astronomy* (Macmillan & Co., 1894), p. 149.
[27] *Ibid.*

these astronomers took the co-efficient $2e - \frac{e^3}{4} = 300'$ nearly; the modern value of it is 377′ nearly. The reason for this is that the moon was observed correctly only at the times of eclipses.[28] During the eclipses or syzygies the evection term of the moon's equation diminishes (numerically) the principal elliptic term by about 76′.

(b) *Epicyclic Construction*: Planetary motion under the epicyclic construction may be explained thus: Let AMP (Fig. 5.5) be the circular orbit of the sun having E, the centre of the earth, as the centre. Let the diameter AEP be the apse line, A be the apogee, and P the perigee. Let M be the mean position of the sun in the orbit. With M as the centre, describe the epicycle UNS which cuts EM at N. Extend EM to cut the epicycle UNS at U. Now the construction for finding S, the apparent sun, is given thus: Make angle $UMS=$ angle MEA; the arc US is measured clockwise, whereas the arc AM is measured counter-clockwise.

From this construction MS is parallel to EA. Along EA towards the apogee A, measure EC equal to MS, the radius of the epicycle. Then CS is a constant length and C a fixed point. Hence the locus of S is an equal circle with the centre at C. Thus both (i) the eccentric and (ii) the epicycle and the concentric combined lead to the same position and orbit of S. It is thus clear that the two assumed constructions shown in Figure 5.5 give the same position

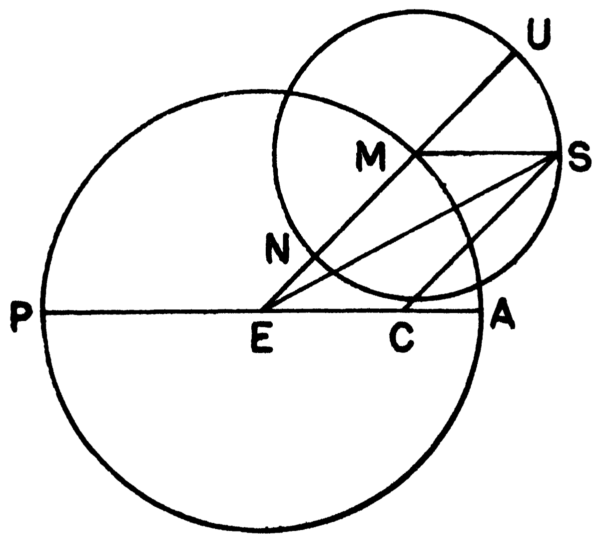


Fig. 5.5

[28]*Khaṇḍakhādyaka*, trans. P. C. Sen Gupta (Calcutta University, 1934), p. 162.

for a planet. The eccentric-circle construction appears to have preceded the epicyclic construction.

With regard to the five superior planets—Mercury, Venus, Mars, Jupiter, and Saturn—Āryabhaṭa I and other Indian astronomers give only one method for finding the apparent geocentric position. Each of these 'star planets' is believed to have a twofold planetary inequality: (i) the inequality of the apsis and (ii) the inequality of the *śīghra*. With regard to the superior planets, the *śīghra* apogee or the *śīghrocca* coincides with the mean position of the sun. As Varāhamihira observes: 'Of the other planets beginning with Mars, the sun is the so-called *śīghra*.[29]

Let $AMSP$ (Fig. 5.6) be the concentric of which the centre E is the same as that of the earth; $A'M_1P'$ be the eccentric circle of the apsis of a superior

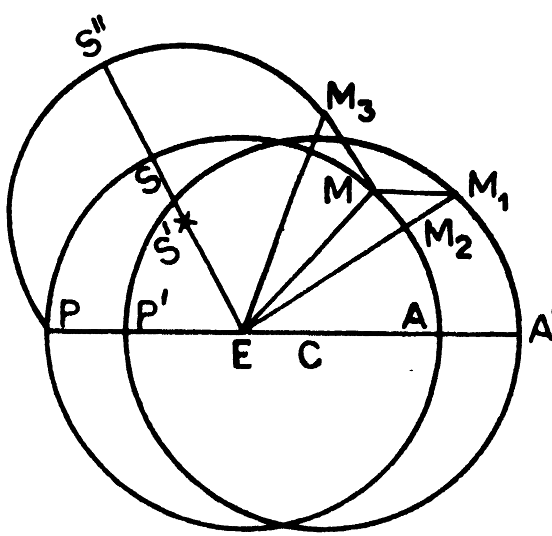


Fig. 5.6

planet of which the centre is C; A, M, S, P be respectively the apogee, mean planet, direction of the *śīghra*, and perigee in the concentric; and A', M_1, P' be respectively the apogee, position of the planet as corrected by the equation of the apsis, and perigee in the eccentric. The arc AM=arc $A'M_1$; MM_1 is parallel and equal to EC. Thus both the eccentric and the concentric are of the same radius.

Here, the mean planet M in the concentric is taken to be deflected to M_1, owing to the true motion in the eccentric circle. Join EM_1; cutting the con-

[29] *Pañca-siddhāntikā*, XVII.1.

centric at M_2. Now let ES be joined and let S' be taken along ES, so that

$$\frac{ES'}{ES} = \frac{\text{śighra periphery of the planet in degrees}}{360}$$

$$= \frac{\text{sun's mean distance from the earth}}{\text{planet's mean distance from the sun or the earth}}.$$

ES' thus determined is called the radius of the *śighra* epicycle of the superior planet.

With S' as the centre and the radius equal to ES or EA, let us describe a circle which is called the *śighra* eccentric, cutting ES produced at S''. Now measure the arc $S''M_3$ in the eccentric equal to SM_2 in the concentric. The apparent superior planet is seen in the direction EM_3 from the earth. This is the construction used in Indian astronomy for calculating the geocentric longitude of any star planet.

It is evident that in the case of a superior planet the eccentric which has S' for the centre and whose radius$=EA=$R—the standard radius for any circular orbit—is the mean orbit of the planet and that S' is the mean position of the sun. In other words, in the case of a superior planet the *śighra* eccentric represents the mean orbit round the sun. If the parallelogram $CES'C'$ is constructed, then an equal circle described with C' as the centre is the apparent eccentric orbit of the superior planet.

In the actual method for calculating the geocentric longitude of a 'star planet' there are four operations, the first two of which have the effect of changing the arc MA or rather the point A.[30] The last two operations relate to the two displacements MM_1 and M_2M_3. We have here followed solely the construction by the eccentric circles; the same geocentric position of a superior planet can as well be obtained by the epicyclic construction.

In describing the method of finding the position of an inferior planet we shall follow the epicyclic construction only. Let E (Fig. 5.7) be the centre of the earth, AMS the orbit of a mean inferior planet or the mean sun, EA the direction of the apogee of apsis, and ES the direction of the *śighra*. The inequality of the apsis takes the mean geocentric planet from M to M_1, so that MM_1 is parallel to EA. Let EM_1 be joined, cutting the concentric at M_2; M_2 is taken as the centre of the *śighra* epicycle, or the real circular orbit in which the apparent planet moves. With M_2 as the centre and the radius of the inferior planet's *śighra* epicycle as radius, the circle NVU is described which is here the *śighra* epicycle or the real circular orbit. In it the radius M_2V is drawn parallel to ES; then V is the geocentric position of the inferior planet. Here the first displacement, MM_1, is due to the inequality of apsis and is for finding the

[30] P. C. Sen Gupta, 'Āryabhaṭīya' (trans.), *Journal of the Department of Letters*, Vol. XVI (Calcutta University, 1927), pp. 36-39.

position of M_2, the centre of the real circular orbit. The idea was that the apparent planet moved in a circular orbit of which the centre was very near the mean position of the sun. The first operation in this construction was calculated to determine the centre of this so-called circular orbit of an inferior planet.

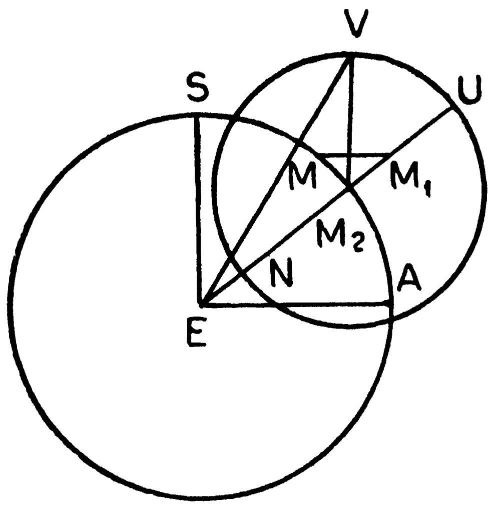


Fig. 5.7

The *śighra* of an inferior planet moves round the earth at the same mean rate in which the inferior planet moves round the sun; hence the line *ES* in the figure is always parallel to the line joining the sun to the mean heliocentric inferior planet, and in our construction it is parallel to M_2V.[31]

Spherical Astronomy: The theory of spherical astronomy of Āryabhaṭa I is contained in the *Golapāda* section of the *Āryabhaṭīya*. Āryabhaṭa I explained the methods of representing planetary motions in a celestial sphere. Such terms as prime vertical, meridian, horizon, hour circle, and equator are defined in this section. Āryabhaṭa I was the first Indian astronomer who referred to the rotation of the earth to explain the apparent diurnal motions of the fixed stars. Some of the stanzas of the *Golapāda* dealing with spherical astronomy together with six of the equations on the subject as found in the *Golapāda* are discussed below. The first two of these rules are as follows:

(i) $R \sin \text{R.A.} = \dfrac{R \cos \omega \times R \sin l}{R \cos \delta}$

(ii) $R \sin \delta = \dfrac{R \sin \omega \times R \sin l}{R}$

[31] *Ibid.*, Vol. XVII, pp. 35-36.

These are the two equations for finding the right ascension and declination of any point on the ecliptic of which the longitude is l. Here ω and δ are respectively the obliquity of the ecliptic and the declination of the point. The first rule is given in stanza 25 of the *Golapāda* which also hints at the second.

The third rule, occurring in stanza 26, states:

(iii) $R \sin \text{(ascensional difference)} = \dfrac{R \times R \sin \phi \times R \sin \delta}{R \cos \phi \times R \cos \delta}$.

Here ϕ is the latitude of the station and δ is the sun's declination. The three aforementioned rules, coupled with stanza 27 of the *Golapāda*, indicate the method by which the duration of the rising of the signs of the zodiac may be found.

According to the fourth rule as given in stanza 28 of the *Golapāda*:

(iv) $R \sin \text{(altitude of the sun)} =$

$$\frac{R \sin \text{(time from sunrise)} \times R \cos \delta \times R \cos \phi}{R \times R}.$$

This is a rough equation connecting the altitude of the sun and the time that has elapsed since sunrise.[32] Stanza 29 shows the method of finding the *śaṅkvagra*, which led to the correct altazimuth equation by subsequent writers, specially Brahmagupta and Bhāskara II.

The next two equations which were correctly obtained by Āryabhaṭa I are given in stanzas 30 and 31 of the *Golapāda* as follows:

(v) $R \sin \text{(sun's amplitude)} = \dfrac{R \sin \omega \times R \sin l}{R \cos \phi}$;

(vi) $R \sin \text{(altitude of the sun in the prime vertical)} =$

$$\frac{R \sin \omega \times R \sin l \times R \cos \phi}{R \cos \phi \times R \sin \phi}.$$

Stanzas 33 and 34 of the *Golapāda* contain the rules for parallax in longitude and latitude as given by Āryabhaṭa I. But they are not intelligible owing to the faulty text. Stanza 35 explains how to perform the *dṛkkarma*[33] operations. The rule for *ākṣa dṛkkarma* is approximately correct, while that for *āyana dṛkkarma* is wrong. Stanzas 39 and 40 accurately express the angular diameter of the earth's shadow at the moon's orbit, and 41 and 42 show the method of finding

[32] The correct equation, occurring in the *Pañca-siddhāntikā* (IV.45-47), was presumably first found by Āryabhaṭa's pupils.

[33] *Dṛkkarma* denotes astronomical operations to find the longitude of the orient point of the ecliptic which rises simultaneously with a planet. The process is divided into two parts: *āyana* and *ākṣa dṛkkarmas*. The first relates to the transformation of the celestial longitude and latitude of the planet into what are called the polar longitude and polar latitude in Indian astronomy. In this case, the polar longitude is the orient ecliptic point for the observer on the equator. The second process reduces the polar longitude of the planet to the orient point of the ecliptic point at the latitude of the observer and is called *ākṣa dṛkkarma*. The first is due to the obliquity of the ecliptic and the second to the latitude of the observer.

half durations of eclipses and of total obscuration. As Āryabhaṭa's rule for *āyana dṛkkarma* is incorrect, his rule for *āyana valana* is also incorrect.

VARĀHAMIHIRA, BRAHMAGUPTA, AND OTHERS

Varāhamihira's redaction of the old *Sūrya-siddhānta* is a wholesale borrowing from the *ārdharātrika* system of astronomy of Āryabhaṭa I.[34] But his work is valuable from the viewpoint of the history of Indian astronomy. He mentions the names of the following astronomers who preceded him: Lāṭadeva or Lāṭācārya, who was a direct pupil of Āryabhaṭa I; Siṁhācārya, of whom we know very little except that he considered the astronomical day to begin from sunrise at Laṅkā;[35] Āryabhaṭa I; Pradyumna, who studied the motions of Mars and Saturn; and Vijayanandin, who made special observations of the planet Mercury.[36] According to the *Brāhmasphuṭa-siddhānta* (XI. 48-51), Vijayanandin was the author of a work called the *Vāśiṣṭha-siddhānta*, perhaps a revision of the old *Vāśiṣṭha-siddhānta* of the *Pañca-siddhāntikā*. It is not quite certain whether Pradyumna and Vijayanandin preceded Āryabhaṭa I.

Brahmagupta (b. A.D. 598) wrote his *Brāhmasphuṭa-siddhānta* in *c.* A.D. 628 and his *Khaṇḍakhādyaka* in A.D. 665. The second work gives easier methods of computation of the longitude of planets according to Āryabhaṭa's *ārdharātrika* system of astronomy. In his first work he has corrected all the erroneous methods of Āryabhaṭa I and has in more than one place corrected the longitude of the nodes, apogees, and other astronomical elements of planets. Indeed, after Āryabhaṭa I the next name of significance is undoubtedly Brahmagupta, who, coming 125 years after the former, did not find much scope for the further development of Indian astronomy. Thus being jealous of the great fame of Āryabhaṭa I, he made some unfair criticisms of his work. Besides his corrections of Āryabhaṭa's system, Brahmagupta's other chief achievements in his *Brāhmasphuṭa-siddhānta* consisted in: (i) finding the instantaneous daily motion of planets affected by both the *manda* and *śīghra* inequalities (II); (ii) ascertaining the correct equations for parallax in longitude and latitude (V.2-5); (iii) working out the altitude of the sun on the S.E. and S.W. verticals on any day (III.54-56); (iv) determining more correct equations for the *dṛkkarmas* (VI.3-4); and (v) giving a more correct expression for the *valanas* (IV.16-18). In addition, in his *Khaṇḍakhādyaka* (IX.8,12-13) he demonstrated the more correct method of interpolation by using the second differences. Indeed, his methods have been accepted by all the subsequent famous astronomers like Bhāskara II and have been incorporated into redactions of the *Siddhāntas*.

Brahmagupta mentions two writers, Śrīṣeṇa and Viṣṇucandra, who were

[34] *Sūrya-siddhānta*, trans. E. Burgess, pp. ix-xii.
[35] *Pañca-siddhāntikā*, XV.18.
[36] *Ibid.*, XVIII. 62.

respectively the authors of new recasts of the *Romaka-* and *Vāśiṣṭha-siddhāntas*. Both these writers lived after Āryabhaṭa I, as they borrowed much from him.

THE ORIGINALITY OF INDIAN ASTRONOMY

Concepts of scientific astronomy in India were not borrowed wholesale from either Babylonian or Greek science. In planetary theory, for instance, the term *śīghra* or the 'apex of quick motion' has not the same meaning as 'conjunction' with which it has been identified. Then the term *mandocca*, the 'apex of slowest motion', does not mean a point farthest from the earth as 'apogee' does, though *ucca* means 'a high place'. Thus the meanings of the terms *śīghrocca* and *mandocca* show some originality of thinking by Indian astronomers. We are not suggesting, however, that the Indian epicyclic astronomy as it was developed by Āryabhaṭa I and his pupils was uninfluenced by Babylonian and Greek sciences. But the problem of discerning how far the Indian astronomers were original as regards planetary theory appears insurmountable. As we have already said, they were *sūtrakāras* or writers of aphorisms who stated only their results but not the methods by which they obtained them. These methods were at first transmitted through generations of teachers, and in the course of ages they were lost. Āryabhaṭa I furnished only one stanza (*Golapāda*, 48) regarding his astronomical methods, which says: 'The day-maker has been determined from the conjunction of the earth (or the horizon) and the sun; and the moon from her conjunctions with the sun. In the same way, the "star planets" have been determined from their conjunctions with the moon.'[37] No other Indian astronomer has left us anything of the Indian astronomical methods. In A.D. 1150 Bhāskara II tried to explain how the number of sidereal revolutions of 'planets' could be verified,[38] but his expositions are not satisfactory and are in places faulty. There is no doubt that Greek astronomy came to India before the time of Āryabhaṭa I. Varāhamihira has given us a summary in his *Pañca-siddhāntikā* of what was known by the name of the *Romaka-siddhānta*, but nothing of the epicyclic theory is found in it. A verbal transmission of that theory together with that of a few astronomical terms from a foreign country was quite possible. It must be said to the credit of Indian astronomers that they determined all the constants anew. Even in the lunar theory, Mañjula (A.D. 932) discovered the second inequality and Bhāskara II the third inequality, viz. 'variation'.[39] The Indian form of 'evection equation' is much better than that of Ptolemy and

[37] It has been shown in a study of the above stanza that by these methods the sidereal periods of the sun, Mars, Jupiter, and Saturn, as well as the synodic month and hence the sidereal months, may be determined. Also the geocentric sidereal periods of Mercury and Venus may be found to be the same as the sidereal period of the sun. See *Bulletin of the Calcutta Mathematical Society*, Vol. XII, No. 3.

[38] *Siddhānta-śiromaṇi, Grahagaṇita, Bhagaṇādhyāya*, 1.5 and commentary thereon.

[39] *Khaṇḍakhādyaka*, pp. 162-70.

stands on a par with that of Copernicus. It is from some imperfections also that this originality may be established. For instance, the early Indian astronomers recognized only one part of the equation of time, viz. that due to the unequal motion of the sun along the ecliptic. It was only in A.D. 1028 that Śrīpati first discovered the part of it which was due to the obliquity of the ecliptic.[40] In Greek astronomy both the parts were detected by Ptolemy. In regard to the methods of spherical astronomy, the Indian astronomers were in no way indebted to the Greeks. The Indian methods were of the most elementary character, while those of Ptolemy were much advanced and more elegant. Yet the Indian astronomers could solve some problems where Ptolemy failed. For instance, they could find the time of day by altitude and the altitude from the sun's azimuth.[41] Thus, although scientific Indian astronomy is dated much later than the time of Ptolemy, barring the mere idea of an epicyclic theory coming from outside India, its constants and methods were all original.

[40] *Siddhānta-śekhara*, ed. Babuaji Misra (Calcutta University), Vol. I (1932), p. xii; Vol. II (1947), pp. xxxiv-xxxviii.

[41] P. C. Sen Gupta, 'Greek and Hindu Methods in Spherical Astronomy', *Journal of the Department of Letters*, Vol. XXI (Calcutta University, 1932). See also *Khaṇḍakhādyaka*, pp. 172-93.

6

ASTRONOMY IN MEDIEVAL INDIA

THE foregoing pages by late Professor P. C. Sen Gupta reproduced from the first edition of the *Cultural Heritage of India* were written in the thirties of the present century when our knowledge of Indian astronomy was largely confined to the works of Āryabhaṭa I, Brahmagupta, Bhāskara II, and a few other ancient astronomers. Sen Gupta himself contributed significantly to our understanding of ancient Indian astronomy through his work on Vedic chronology; by editing, translating, and commenting upon the texts of Āryabhaṭa I and Brahmagupta; and by writing various articles on the subject including an admirable introduction to Burgess's translation of the *Sūrya-siddhānta* published by Calcutta University. During the last forty to fifty years, specially after World War II, several new astronomical manuscripts, both original works and commentaries, have been critically edited, translated, and commented upon by a number of able scholars in India and abroad throwing new light on the subject. It now appears that the originality of Indian astronomy did not cease with the astronomical and mathematical productions of Bhāskara II in the beginning of the twelfth century, that both before and after him important works and commentaries were produced, and further that the medieval period from the twelfth to the eighteenth century, though largely marked by the secondary activities of the commentators, did occasionally produce brilliant minds with significant contributions to their credit.

PERIOD BETWEEN BRAHMAGUPTA AND BHĀSKARA II

Between the period of Brahmagupta and that of Bhāskara II, we must notice the works of Bhāskara I, Govindasvāmin, Śaṅkaranārāyaṇa, Āryabhaṭa II, Śrīpati, and Śatānanda.

Bhāskara I, who flourished around *c.* A.D. 600, was a contemporary of Brahmagupta and possibly the greatest exponent of Āryabhaṭa's *audayika* and *ārdharātrika* systems of astronomy. From stray and insufficient references in his works it is not possible to determine with certainty his place of birth. His association with both the Aśmaka country in South India, possibly Kerala, and Saurāṣṭra in western India is equally probable. His fame rests on three works, namely, the *Mahābhāskarīya*, the *Laghubhāskarīya*, and a running commentary (*bhāṣya*) on Āryabhaṭa I. Though based on Āryabhaṭa's system, the *Mahābhāskarīya* is a full-fledged work dealing with (i) mean longitudes of planets and indeterminate analysis, (ii) methods of finding true longitudes

(in Chapters II and IV), (iii) the three questions relating to time, place, and direction, and discussion of spherical trigonometry, latitudes, and longitudes of junction stars, (iv) solar and lunar eclipses, (v) rising, setting, and conjunction of planets, (vi) astronomical constants taken from his master's two systems, and (vii) lunar day and miscellaneous examples. He gives a new method called *pratyabda-śodhana* for finding mean longitudes of planets, the conjunction points (*śīghra*) of Venus and Mercury, and the moon's perigee and node. He also gives a full discussion of the method of indeterminate analysis with numerous examples and its relation with astronomical problems. The *Laghubhāskarīya*, as the name implies, is a shorter manual intended as a text for the beginner.

Govindaśvāmin (*c.* 800-850) is mainly noted for his commentary on the *Mahābhāskarīya* and, therefore, for his mastery of the Āryabhaṭan system. He was the court astronomer of King Ravivarman of Kerala. Besides the commentary, he is credited with an original work on astronomy and mathematics called *Govindakṛti* of which references are known but the original manuscript is still untraceable.[1] Govindasvāmin's disciple and younger contemporary, Śaṅkaranārāyaṇa (*c.* 825-900), also rose to eminence through his commentary on the *Laghubhāskarīya*, and was appointed chief court astronomer of Ravivarman of the Cera dynasty of Kerala (possibly the same king who patronized Govindasvāmin).

Vaṭeśvara (b. 880), whom al-Bīrūnī referred to as Vitteśwara in his *India* (*Kitāb Taḥqīq mā li-'l-Hind*), was another Āryabhaṭan scholar who flourished in North India. We learn from his own statement that he was the son of Mahādatta Bhaṭṭa, a native of Ānandapura in the Punjab. His *Siddhānta* is a voluminous work divided into three main sections, each subdivided into a number of chapters. It is well known that Brahmagupta in his *Brāhmasphuṭa-siddhānta*, written at a young age, indulged in invectives against Āryabhaṭa for his sophisticated theories, e.g. the rotation of the earth and the equal division of the *mahāyuga*, which occasioned bitter criticism of the Arab indologist and encyclopaedic scholar al-Bīrūnī in spite of his overall admiration for Brahmagupta. About 250 years later Vaṭeśvara returned similar invectives against Brahmagupta in a full chapter(X).[2]

Āryabhaṭa II (*c.* 950) did not have the merit of his namesake and illustrious predecessor. His *Mahāsiddhānta* is a compendious work based largely on orthodox views, showing some originality in the treatment of indeterminate equations. The reputation of versatile Śrīpati (*c.* 999), son of Nāgadeva, is based on his (i) *Dhīkoṭi*, a Karaṇa work on the *Āryabhaṭīya*, (ii) a fuller astronomical work

[1] K. V. Sarma, *A History of the Kerala School of Hindu Astronomy* (Vishveshvaranand Institute, Hoshiarpur, 1972), pp. 44-45.

[2] See *Vaṭeśvara-siddhānta*, ed. Ram Swarup Sharma and Mukunda Mishra, Part I (Indian Institute of Astronomical and Sanskrit Research, New Delhi, 1962).

entitled *Siddhānta-śekhara*, and (iii) a mathematical treatise, *Gaṇitatilaka*. He is credited with the discovery of the moon's second inequality. Śatānanda (*c*. eleventh century) hailed from Puri in Orissa and wrote a Karaṇa work called *Bhāsvatī*, more or less in the style of the *Sūrya-siddhānta*. This work enjoyed great popularity among the astronomers and almanac-makers of the eastern region.

PERIOD FROM THIRTEENTH TO EIGHTEENTH CENTURY

Despite a few original works, this period witnessed by and large the production of a number of commentaries and secondary works. It would, however, be unrealistic to characterize this period as one of commentaries only. This type of literature started appearing from the eighth or ninth century, if not earlier. Utpala was a great commentator who specialized on Varāhamihira. In the ninth century Pṛthūdakasvāmin (*c*. 860) produced two important commentaries on Brahmagupta, namely, the *Brahmasiddhānta-vāsanābhāṣya* and *Khaṇḍakhādyaka-vivaraṇa*. In the same century Govindasvāmin and Śaṅkaranārāyaṇa were popularizing in the South the works of Bhāskara I and thereby Āryabhaṭa's astronomical system.

In the thirteenth century another Āryabhaṭan scholiast, Sūryadeva Yajvan (*c*. 1191-1250) of the Nidhruva *gotra*, hailing from Kerala, produced a number of commentaries on the *Āryabhaṭīya*, Mañjula's *Laghumānasa*, and the works of Bhāskara I. His commentary on Āryabhaṭa has recently been published, in the critical edition of *Āryabhaṭīya*, by the Indian National Science Academy on the occasion of the fifteen hundredth birth anniversary of the great savant. Sūryadeva was also an astrologer of repute and commented on Varāhamihira's *Mahāyātrā* and Śrīpati's *Karmapaddhati*.

The fourteenth and fifteenth centuries are remarkable for the production of both commentaries and original works. Mahendra Sūrī (*c*. 1320), a disciple of Madana Sūrī and native of Bhṛgupura in North India, was one of the principal court astronomers of Firozshah Tughluq. The Sūrī family mastered the theory and technique of the astrolabe, the versatile astronomical instrument and computer of which we shall say more in what follows. This is borne out by the *Yantrarāja* or *Yantrarājagama* compiled by Mahendra Sūrī from Persian sources. Malayendu Sūrī, his disciple, prepared a useful commentary on the tract.

In the South (Kerala) flourished Mādhava of Saṅgamagrāma (*c*. 1340-1425), who later on received the appellation 'Master of Spherics' (*golavid*). In his *Veṇvāroha* he developed an easy and facile procedure for determining the true position of the moon every 36 minutes. The motion of the moon is not only the fastest among planets and stars, but is marked by maximum and rapid changes which render extremely difficult the determination of its correct position at any intermediate time during the day. He developed an accurate

moon-mnemonics, correct to the second, which gradually became widely accepted by Keralan astronomers. This ingenious method became the subject of several tracts, e.g. the *Candra-sphuṭāpti*, *Veṇvārohakriyā*, and *Dṛg-veṇvārohakriyā*, all anonymous, and another work, *Veṇvārohāṣṭaka*, ascribed to Putumana Somayāji.[3] In the *Veṇvāroha* Mādhava uses an epoch beginning from A.D. 1400 on the basis of which his time has been ascertained without much ambiguity. The *Veṇvāroha* is not his only work. He is credited with several other works such as the *Lagnaprakaraṇa*, a table of moon-mnemonics, *Mahājyānayana-prakāra*, *Madhyamānayana-prakāra*, *Agaṇita*, and *Agaṇita-pañcāṅga*, about the definite identification of which some disputes still persist.

Parameśvara (*c.* 1360-1455), another versatile astronomer and prolific commentator of Kerala, developed a *dṛk* system of computation following Haridatta's earlier *parahita* system with a view to ensuring better agreement between observations and theoretical computations. A disciple of Rudra, he belonged to a family of astronomers who lived in the village of Allatur (Aśvatthagrāma, lat. 10°15′) near the confluence of the river Nīlā with the Arabian Sea. His original works include *Dṛggaṇita* (1430), *Goladīpikā* (1443), *Vākyakaraṇa*, *Grahaṇāṣṭaka*, *Grahaṇamaṇḍana*, and *Candracchāyā-gaṇita*, most of which are small but useful tracts. His detailed running commentaries on the *Āryabhaṭīya*, *Mahābhāskarīya*, *Laghubhāskarīya*, *Sūrya-siddhānta*, *Laghumānasa*, and *Līlāvatī* clearly show his mastery of traditional astronomy of the Siddhāntic period and at the same time his indefatigable energy as a commentator. From the point of view of clarity and brevity of expression he was probably unrivalled.

Parameśvara's son, Dāmodara (*c.* 1410-1510), imbibed his father's interest and scholarship in astronomy. Dāmodara's works have not yet come to light, but that he did write certain astronomical works is attested by the statements of his illustrious disciple Nīlakaṇṭha Somayāji (1444-1545). Nīlakaṇṭha is also known by other titles such as 'Somasutvan', 'Somasut', and their Malayalam version 'Comatiri'. As a commentator and innovator, he attained widespread fame which compares well with that of Parameśvara. From the scanty biographical details given in the colophon of his commentary on the *Gaṇita* section of the *Āryabhaṭīya* and from a Malayalam work, *Laghurāmāyaṇam*, we learn that he was a Namputiri of the Garga *gotra* and hailed from Śrīkundapura or Śrīkundagrāma (Malayalam, Tṛ-k-kaṇṭi-yūr) near Tirur in South Malabar, a place which in medieval times rose to be an important seat of Sanskrit learning, specially astronomy and mathematics. As to his teachers, besides Dāmodara, he mentions another preceptor, Ravi, versed in Vedānta. In his *Siddhānta-darpaṇa* he refers to these two teachers as follows: *Śrīmaddāmodaraṁ natvā bhagavantaṁ raviṁ tathā/yatprasādānmayā labdhaṁ jyotiścaritamucyate* (I bow down with reverence to my teachers Dāmodara and Ravi by

[3] Sarma, *op. cit.*, p. 51.

whose grace I have acquired the knowledge of astronomy which I am going to discuss here).

Of the several works penned by Nīlakaṇṭha, special mention may be made of *Golasāra* (Essence of the Sphere), *Siddhānta-darpaṇa* (Mirror of Astronomy), *Candracchāyā-gaṇita* (Computations of the Moon's Shadow), *Tantrasaṅgraha* (Collection of Astronomical Works), and *Āryabhaṭīya-bhāṣya* (Commentary on the *Āryabhaṭīya*).[4] Moreover, he wrote commentaries on his own *Siddhānta-darpaṇa* and *Candracchāyā-gaṇita*. Some other minor works of Nīlakaṇṭha include the *Grahaṇa-nirṇaya* (Determination of Eclipses) and *Sundararāja-praśnottara* (a debate with the Tamil astronomer Sundararāja on the method of *vākyakaraṇa* and other astronomical procedures). And this by no means exhausts the list of his writings, some of which are yet to be traced.

Nīlakaṇṭha's commentary on the *Āryabhaṭīya* is a masterpiece despite several other commentaries on this text by renowned astronomers like Bhāskara I, Parameśvara, and Sūryadeva Yajvan. He not only elucidated with singular clarity many cryptic verses composed in the *sūtra* style, but expressed his profound admiration for Āryabhaṭa for his insistence on periodic observations in order to ensure accuracy. 'The picture of Āryabhaṭa which Nīlakaṇṭha presents', observes K. V. Sarma, 'is appropriately enough, that of an observer and experimenter. Referring to certain methods enunciated by Āryabhaṭa, Nīlakaṇṭha says, "The principles have all been implied in (the *sūtra* beginning with) the three words: The Sun through the conjunctions of the Sun and the Earth, (the Moon) through the conjunctions of the Sun and the Moon, etc.... Employing the principles implied here, it is possible for the intelligent to conduct the experiments, duly." Nīlakaṇṭha is more explicit when he says: "Hence Āryabhaṭa has composed his *Siddhānta* only to exemplify the methods of experimentation and expound the corpus of principles necessary therefor."'[5] Nīlakaṇṭha himself kept up this spirit and advocated without reserve the importance of astronomical observations, specially during eclipses. He emphasized that such 'experimentation should continue to be done by successive generations of disciples and grand disciples' (*śiṣyāṇāṁ grahagatiparīkṣāsāmarthyāpādanameva śāstraprayojanam*).

Interestingly enough, Roger Billard in his recent computer studies of several Indian astronomical texts has confirmed that these texts were from time to time actually based on observations which were remarkably accurate for the times as also for the instruments then available. About Āryabhaṭa's

[4] *Ibid.*, pp. 55-57.

[5] *Jyotirmīmāṁsā*, ed. K.V. Sarma (V.V.B. Institute of Sanskrit and Indological Studies, Hoshiarpur, 1977). Nīlakaṇṭha's actual statements run as follows: (a) *Padatrayeṇa sakalā yuktayaḥ pradarśitāḥ kṣitiraviyogād dinakṛd ravīnduyogāditi; atroktābhiryuktibhireva buddhimadbhiḥ samyak parīkṣaṇaṁ kartuṁ śakyam.* (b) *Tasmādāryabhaṭaḥ parīkṣāprakāraṁ tadupayogiyuktikalāpaṁ ca pradarśayitumeva siddhāntaṁ cakāra.*

observations he writes: One cannot fail to notice the astonishing precision of these mean positions as a whole during the period of their observations. This precision certainly represented the limit of accuracy of ancient astronomical methods, of the instruments in use, and of the mathematical models then available. That is to say, despite the speculation of the *yuga* system, Āryabhaṭa is certainly one of the greatest figures in the history of astronomy.[6]

In the fifteenth-sixteenth centuries, although the extreme South—Kerala and Tamil countries—had the pride of place in astronomical research and in keeping the subject alive through commentaries, the astronomers of countries south and north of the Vindhyas were no less active. Gaṅgādhara, author of *Candramāna* (1434), lived south of the Vindhyas and Makaranda of Vārāṇasī, who compiled handy tables based on the *Sūrya-siddhānta*, became popular with almanac-makers, as did Lakṣmīdāsa for his *Gaṇitatattva-cintāmaṇi* (1500), a commentary on the *Siddhānta-śiromaṇi*[7] of Bhāskara II. We also hear of several families of astronomers and mathematicians, some of whom were prolific writers. Thus Jñānarāja (*c.* 1503), son of Nāganātha, flourished at Pārthapura, a small village on the Godāvarī, and wrote an astronomical work, the *Siddhānta-sundara,* in eighteen chapters. His son Sūryadāsa popularized *Līlāvatī* and *Bījagaṇita* of Bhāskara II. More versatile was Gaṇeśa Daivajña (*c.* 1507) of Nandigrāma near Bombay, whose activities and range of scholarship can be gauged from his works such as *Grahalāghava, Bṛhattithi-cintāmaṇi, Laghutithi-cintāmaṇi,* and *Siddhānta-śiromaṇi-vyākhyā.* Divākara, a Maharashtrian Brāhmaṇa, son of Rāma and student of Gaṇeśa Daivajña, founded a line of astronomers whose activities encompassed four generations.[8] The family hailed from Golagrāma on the northern bank of the Godāvarī. Three of Divākara's five sons, Viṣṇu, Mallāri, and Viśvanātha, produced Karaṇa works and commentaries on the *Grahalāghava, Sūrya-siddhānta,* and a few other works. Viśvanātha was the most active of the five. Divākara's grandson Nṛsiṁha (by Śrīkṛṣṇa) worked at Vārāṇasī and wrote commentaries on the *Sūrya-siddhānta* and *Siddhānta-śiromaṇi.* Nṛsiṁha (*c.* 1586) had four sons: Divākara, Kamalākara, Gopīnātha, and Raṅganātha. Kamalākara's (*c.* 1616) fame rests on his *Siddhānta-tattvaviveka,* a voluminous exposition of the *Sūrya-siddhānta* written in verse in which was incorporated much material from Arab astronomical and geometrical texts. Raṅganātha (*c.* 1640) produced a running and detailed

[6] '*On ne manquera pas de remarquer l'e tonnante précision des ces ensembles de positions moyennes pendant la période des observations. Cette précision était certainement à la limite des moyens de l'astronomie ancienne, à la limite de ses instruments et de ses modeles mathématiques. C'est à dire des à present qu'en dépit de la spéculation yuga, Āryabhaṭa est certainement l'une des grandes figures de l'histoire de l'astronomie.*'—Roger Billard, *L'Astronomie Indienne* (École Française d'Extreme-Orient, Paris, 1971), p. 83.

[7] See S. N. Sen, 'Astronomy', *A Concise History of Science in India*, ed. D. M. Bose, S. N. Sen and B. V. Subbarayappa (Indian National Science Academy, 1971), pp. 99ff.

[8] *Ibid.*

commentary on the *Sūrya-siddhānta*, which was used by Burgess in preparing his well-known translations and notes.

It is interesting to note that while Āryabhaṭa was popular among, and dominated the astronomical thinking of, scholars in the South, the *Sūrya-siddhānta* attracted the greatest attention of the astronomers of the North. The works of Bhāskara II, *Siddhānta-śiromaṇi*, *Līlāvatī*, and *Bījagaṇita*, were popular throughout India. By comparison, the neglect of Brahmagupta and his scholiasts and of a few other works of merit is not easy to understand.

With Kamalākara and Raṅganātha we step into the seventeenth century. From the time of Mahendra Sūrī in the fourteenth century up to that of Kamalākara in the seventeenth, during which some astronomers were closely associated with the House of Tughluqs and later on of the Moguls, many opportunities arose for the exchange of astronomical and mathematical ideas between the two streams of scholarship, of which the fullest advantage was obviously not taken. In my judgement this poverty was due largely to India's failure to produce a scholar of the rank of al-Bīrūnī among either the Hindus or the Mohammedans. A better synthesis was attempted towards the end of the seventeenth and the beginning of the eighteenth centuries under the inspiring patronage of Sawāi Jai Singh II (1686-1734), who was himself an accomplished astronomer and was able to attract a number of distinguished scholars of different religious faiths. More of this later.

Nīlakaṇṭha was succeeded in the South by several astronomers who continued the tradition of preparing commentaries as well as independent works between the sixteenth and eighteenth centuries. Śaṅkara Vāriyar (*c.* 1500-1560), a disciple of Nīlakaṇṭha, produced a commentary entitled *Laghuvivṛti* on the *Tantra-saṅgraha*. His contemporary, Jyeṣṭhadeva, (*c.* 1500-1610) is noted for his *Yuktibhāṣā*, a popular work on mathematics and astronomy in Malayalam. There is also a Sanskrit version of the work under the title *Gaṇita-yuktibhāṣā*, whose authorship is also ascribed to him. Then we have another popular yet comprehensive astronomical treatise in ten chapters, the *Karaṇapaddhati* by an anonymous Somoyāji of the Putumana family of Śivapuram (Trichur), who flourished between *c.* 1660 and 1740. Its wide popularity is attested by the availability of a number of commentaries in Malayalam, Tamil, and Sanskrit. Putumana also wrote a number of other astronomical tracts, e.g. the *Nyāyaratna*, *Veṇvārohāṣṭaka*, and *Pañcabodha*.

ORIGINALITY OF MĀDHAVA, NĪLAKAṆṬHA, *YUKTIBHĀṢĀ*, AND *KARAṆAPADDHATI*

We have seen that Mādhava of Saṅgamagrāma was recognized in the medieval South as the *golavid* or 'master of spherics'. It appears that from his time efforts were made to determine more accurate values of π and trigonometrical functions such as $\sin\theta$, $\cos\theta$, etc. This led to the discovery of a number

of series, generally attributed to Taylor, Gregory, and others, several centuries before these appeared in European mathematical works.

The well-known Taylor series is expressed as follows:

$$f(x+\theta)=f(x)+\theta f'(x)+\frac{\theta^2}{2!}f''(x)+\dots$$

Its particular cases are:

$$\sin(x+\theta)=\sin x+\frac{\theta}{R}.\cos x-\frac{\theta^2}{2R^2}.\sin x$$

$$\cos(x+\theta)=\cos x-\frac{\theta}{R}.\sin x-\frac{\theta^2}{2R^2}.\cos x.$$

These particular cases are derivable from rules given by Mādhava and fully discussed by Nīlakaṇṭha. Thus in his commentary on the *Āryabhaṭīya* and in his *Tantrasaṅgraha*, Nīlakaṇṭha gives the rule,[9] which, as translated by R. C. Gupta, reads:

> 'Placing the (sine and cosine) chords nearest to the arc whose sine and cosine chords are required, get the arc difference to be subtracted or added. For making the correction 13751 should be divided by twice the arc difference in minutes and the quotient is to be placed as the divisor. Divide the one (say sine) by this (divisor) and add to or subtract from the other (cosine) according as the arc difference is to be added or subtracted. Double this (result) and do as before (i.e. divide by the divisor). Add or subtract the result (so obtained) to or from the first sine or cosine to get the desired sine or cosine chords.'[10]

Other forms of sine and cosine series in ascending odd and even powers of the arc or angle, given below and attributed to Newton (1642-1727), have been traced to Mādhava (*c.* 1340-1425) and fully elaborated in the *Yuktibhāṣā* and the *Karaṇapaddhati*:

$$\sin x = x \quad \frac{x^3}{3!}+\frac{x^5}{5!}.$$

[9] *Iṣṭadoḥkoṭidhanuṣoḥ svasamīpasamīrite.*
Jye dve sāvayave nyasya kuryādūnādhikaṁ dhanuḥ;
Dvighna-talliptikāptaika-śaraśaila-śikhīndavaḥ.
Nyasyācchedāya ca mithastatsaṁskāravidhitsayā;
Chittvaikāṁ prāk kṣipejjahyāt taddhanuṣyadhikonake.
Anyasyāmatha tāṁ dvighnāṁ tathāsyāmiti saṁskṛtiḥ;
Iti te kṛtasaṁskāre svaguṇau dhanuṣostayoḥ.

[10] See 'Second Order Interpolation in Indian Mathematics up to the Fifteenth Century', *Indian Journal of History of Science*, IV (1969), pp. 86-98.

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} \cdots$$

Nīlakaṇṭha in his *Āryabhaṭīya-bhāṣya* discussed the irrationality of π and gave, without proof, the expression

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \cdots$$

This series, attributed to James Gregory (1638-75) in Europe, has been traced to Mādhava to whom is ascribed the following verse regarding the circumference of a circle:

> *Vyāse vāridhi-nihate rūpahṛte vyāsasāgarābhihate;*
> *Tri-śarādi-viṣamasaṁkhyā-bhaktamṛṇaṁ svaṁ pṛthakkramāt kuryāt.*

Translated, the verse reads: 'Multiply the diameter by 4. Alternately, deduct from and add to it four times the diameter divided by the odd integers 3, 5, etc. (to get the circumference).'

This means,

$$\pi d = 4d - \frac{4d}{3} + \frac{4d}{5} - \cdots$$

$$\text{or } \frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \cdots$$

A proof of this expression is given in the *Yuktibhāṣā* through three lemmas as follows:[11]

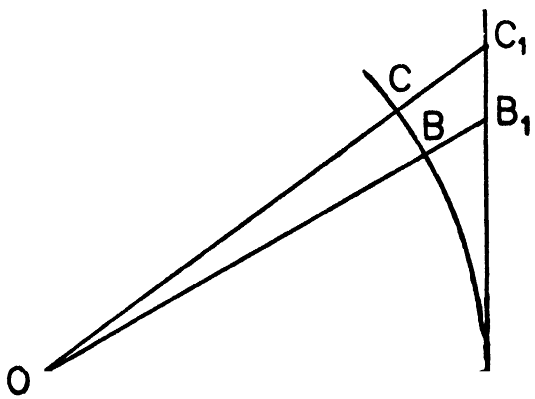


Fig. 6.1

[11]For a fuller mathematical proof see C. T. Rajagopal, 'A Neglected Chapter of Hindu Mathematics', *Scripta Mathematica*, XV, Nos. 3 and 4 (1949), pp. 201-9. See also C. T. Rajagopal and T. V. Vedamurthi Aiyar, 'On the Hindu Proof of Gregory's Series', *Scripta Mathematica*, XVII (1951), pp. 65-74.

Lemma 1: If BC (Fig. 6.1) be a small arc of a circle of unit radius with centre O and if OB and OC be produced to meet the tangent at any point A of the circle in points B_1 and C_1 respectively, then the arc BC is approximately given by

$$\text{arc } BC \simeq \frac{B_1 C_1}{1+AB_1^2};$$

Lemma 2:

$$\text{arc tan } t = \lim_{n \to a} \sum_{r=0}^{n-1} \frac{t/n}{1+(rt/n)^2},$$

$$|\text{arc tan } t| \leq \frac{\pi}{4};$$

Lemma 3:

$$\lim_{n \to a} \frac{1}{n^{p+1}} \sum_{r=0}^{n-1} r^p = \frac{1}{p+1}.$$

From these lemmas the *Yuktibhāṣā* easily derives the following relationship:

$$\text{arc tan } t = t - \frac{t^3}{3} + \frac{t^5}{5} - \ldots, \quad |t| \leq 1.$$

This relationship is also found in the *Karaṇapaddhati*.[12]

These π, sine, cosine, and tangent series were found in Europe by mathematicians like Roberval (1634), Gregory (1638-75), Newton (1642-1727), and Leonhard Euler (1707-83). Indian mathematicians of the fourteenth and fifteenth centuries had already hit upon and developed these series for purposes of refinement of their astronomy. In this connection we must recall the great contribution of C. M. Whish, who first identified these series in the *Tantrasaṅgraha*, *Yuktibhāṣā*, *Karaṇapaddhati*, etc.[13]

VĀKYAM METHOD OF COMPUTATION OF ECLIPSES

An interesting and rapid method of mechanical computation of eclipses was developed by Tamil calendar-makers. This involved the use of shells to

[12] *Ibid.*

[13] C. M. Whish, 'On the Hindu Quadrature of the Circle and the Infinite Series of the Proportion of the Circumference to the Diameter in the Four Śastras etc.', *Transactions of the Royal Asiatic Society of Great Britain and Ireland*, V, No. 3 (1835), pp. 509-23.

represent various numbers and their sexagesimal fractions and artificial words and syllables for memorizing the entire lunar and solar tables required for such purposes. The French astronomer Le Gentil, who visited Pondicherry for observing the transit of Venus during 1769, spent some time in India, studied Indian astronomy from Tamil calendar-makers, and recorded the results of his study in his *Mémoire sur l'Inde.* The study was not based on any manuscript material but on oral information conveyed to him. In 1825 John Warren, an astronomer under the East India Company, followed the example of Le Gentil in compiling his *Kālasaṁkalita* (with the subtitle 'A Collection of Memoirs on the Various Modes According to which the Nations of the Southern Part of India Divide Time'). He obtained information from one Sashia, a calendar-maker of Pondicherry, whom he found after a long search. This Sashia showed him how to compute a lunar eclipse with the help of shells arranged on the ground and from a number of tables which he reproduced from memory with the help of a few artificial words and syllables (*vākyam*). In fact, he computed the lunar eclipse of 31 May-1 June of 1825 with an error of +4 minutes for the beginning, −23 minutes for the middle, and −52 minutes for the end. The various numbers gathered from such sources and the tables compiled on the basis of oral information were recently studied by Neugebauer[14] and Van der Waerden,[15] giving a very clear exposition of the *vākyam* process.

To predict eclipses it is necessary to compute the longitudes of the sun and the moon and also the occurrence of the moon at the node. In the *vākyam* process the Tamil calendar-makers start with a given year and a given longitude of the sun. This epoch is the Kaliyuga beginning 18 February 3101 B.C. Then there are sets of numbers indispensable for computations. These are:

$$
\begin{aligned}
V &= 1600984^{d} & \qquad v &= 212°0'7'' \\
R &= 12372^{d} & \qquad r &= 297°48'10'' \\
C &= 3031^{d} & \qquad c &= 337°31'1'' \\
D &= 248 & \qquad d &= 27°44'6''.
\end{aligned}
$$

Van der Waerden has shown that the number V (1600984 days) represents the *ahargaṇa,* that is, the number of civil days that elapsed from the beginning of the Kaliyuga up to 22 May of A.D. 1282. He has further shown that the *vākyam* process is applicable only after this date, and that it was therefore developed towards the end of the thirteenth century. The numbers represented by R, C, and D are each an approximate multiple of the anomalistic month $27\frac{5}{9}$ days

[14] O. Neugebauer, 'Tamil Astronomy—A Study in the History of Astronomy in India', *Osiris*, X (1952), pp. 252-76.

[15] B. L. Van der Waerden, 'Tamil Astronomy', *Centaurus*, IV (1955-56), pp. 221-34.

(or 27; 33, 16, 26, 11 days in sexagesimal fractions) and contain 449, 110, and 9 such months. These three periods are further related by

$$R=4C+D.$$

The figures in degrees, minutes, and seconds represented by v, r, c, and d are the corresponding motions of the moon. To find the longitude of the moon the *ahargaṇa* a from the beginning of the Kaliyuga up to the date of the eclipse is calculated by the usual methods discussed in all Indian astronomical texts. Then a is divided by V, the remainder by R, the remainder by C, and the remainder of the last division by D. In the example given by Le Gentil for the lunar eclipse of 23 December 1768, the *ahargaṇa* is 1, 778, 701 and the respective quotients are 1, 14, 1, and 5, the last remainder being 238 days. Therefore, a can be written as:

$$a=V+14R+C+5D+238.$$

In the next operation the quotients of the divisions by V, R, etc. are multiplied by v, r, etc. so as to obtain the sum

$$v+14r+c+5d.$$

To this sum is added the motion of the moon during the remaining 238 days. This last quantity to be added is taken from a lunar table given by Robert Penn Warren (b.1905) under the description 'Daily Motion of the Moon During the 248 Days'. The final result gives the longitude of the moon. This method of calculation is the *vākyam* process.

Waerden verified that by applying the same process, the longitude of the moon for *ahargaṇa* 1600984, i.e. for V, worked out exactly to 212°0′7″ as given for v.

For computing longitudes of the sun, Warren has given solar tables which, upon critical analysis, reveal the use of the epicyclic model of finding inequality such as we meet with in the *Āryabhaṭīya*. In other words, trigonometrical methods introduced into Indian astronomy from the time of Āryabhaṭa were in use in these computations as well.

SYNTHESIS BETWEEN HINDU AND ARABIC ASTRONOMY

Reference has already been made to sporadic efforts on the part of Hindu astronomers to incorporate elements of Arabic astronomy and mathematics in Sanskrit works. At least there were ample opportunities for studying Greek works in Arabic translations. In 1259 Hulagu Khan, after the conquest of Persia and establishment of his capital in Marāgha, south of Tabriz, decided to set up on the top of a hill near his new capital an astronomical observatory. With royal patronage and the devoted labour of a number of leading astronomers of his time, the observatory developed into a fine and most well-equipped centre

for first-rate astronomical work. Nasir al-Din aṭ-Ṭusī, a renowned astronomer and mathematician, was its first director, and the Syrian engineer and astronomer al-Dimiskī, as well as al-Khalātī of Tiflis, al-Marāghī, al-Maghribi, Abū'l Farāz, ibn al-Futī, and several other astronomers and mathematicians worked here and produced the famous astronomical table *al-Ilkhānī*. It also built up an unrivalled library. Unfortunately the observatory did not last long, for we do not hear further about it from the fourteenth century onward. In the following century Ulugh Beg, another Mongol prince in the direct line of Tamerlane and great patron of learning, particularly of astronomy, compensated for the decline of Marāgha by establishing another grand observatory in Samarkand in Central Asia.

These examples had some effect in India only in the beginning of the eighteenth century when Sawāi Jai Singh II (1686-1734), an able statesman and astronomer, decided to build in Jaipur, Delhi, Ujjain, and a few other places observatories equipped with masonry and other instruments for the purpose of making more accurate observations and preparing more reliable astronomical tables. In all this he followed the methods and practices of Arab astronomers, retaining at the same time many standard methods given in traditional Sanskrit texts. His masonry instruments included a giant right-triangular gnomon fitted with a graduated quadrant called *Samrāṭ Yantra*; a hollow hemispherical dial, the *jai prakāś*, provided on its concave surface with a number of coordinates; a cylindrical instrument called *Rāma Yantra*, provided with graduations on its inside wall and on the floor believed to be a type of cylindrical astrolabe; and other instruments to serve the purpose of the meridian circle, meridional arc, zodiacal circle, etc. Jai Singh greatly appreciated and valued the small brass instrument called the 'astrolabe' in the manufacture of which Islamic instrument-makers had specialized. He encouraged fabrication of such instruments with Sanskrit inscriptions and himself wrote a small tract on the subject.

The research programme he and his able astronomers and observers undertook included the compilation of an improved astronomical table, *Zīj muhammad shāhī*, and translation into Sanskrit of Ptolemy's *Almagest*, Euclid's *Elements*, and a few other texts from their Arabic versions. The first two were rendered by Jagannātha (b. 1652) who, at the instance of his patron, mastered Arabic and Persian to carry out this important task. Jai Singh also came in contact with a number of Christian missionaries and learnt from them the progress made in astronomy through new types of instruments such as the telescope. He took steps to procure through Jesuit channels the latest astronomical works by European authorities. We know from Tieffenthaler, a Jesuit missionary who visited India just after the death of Jai Singh, that many Jesuit astronomers, including himself, had intended to work in Jai Singh's observatories and initiate a process of exchange of ideas and methods of immense consequence for the future develop-

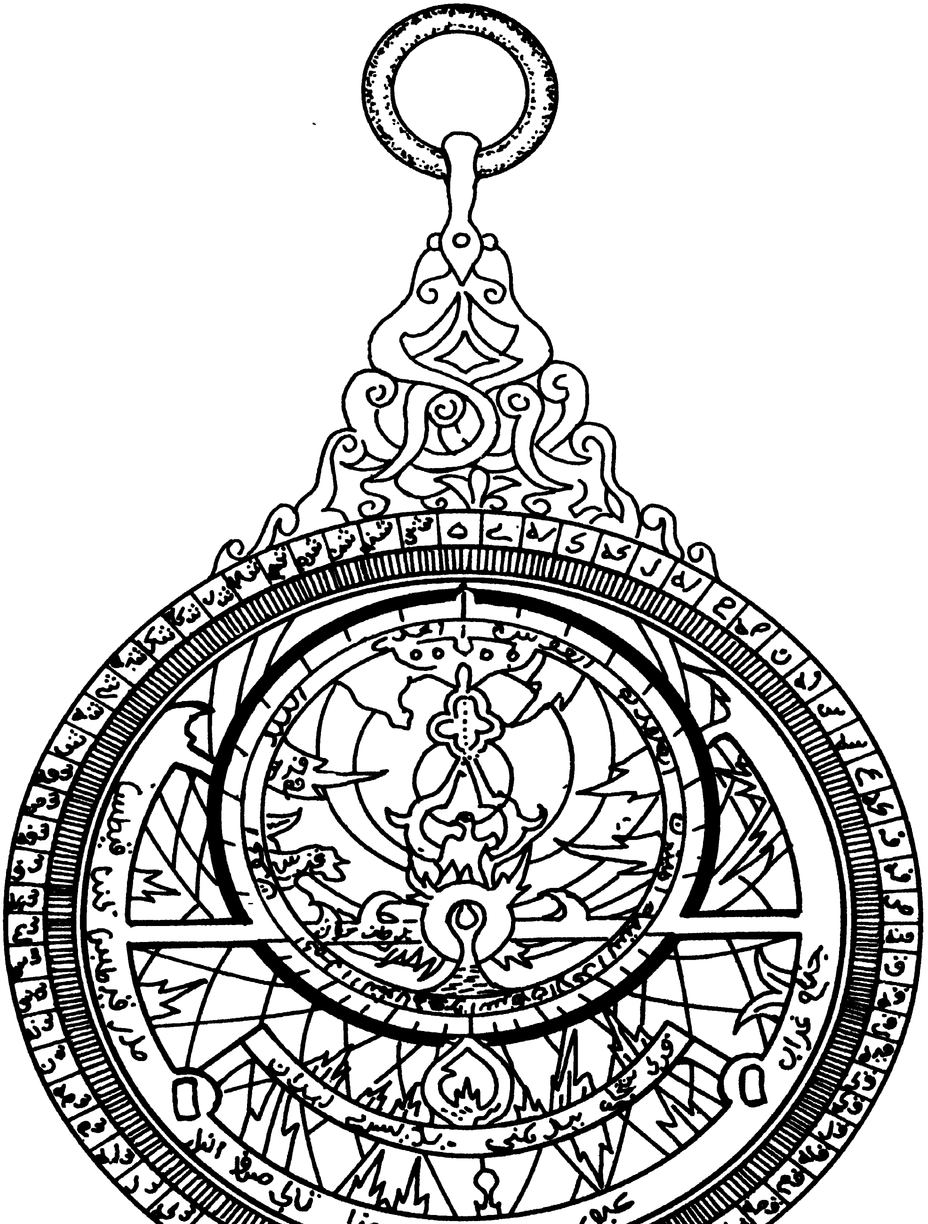
ment of Indian astronomy. That, however, was not to be due to the premature death of the patron and astronomer king and the darkening political clouds soon to engulf the country into a century of strife and uncertainty.

The astrolabe to which reference has been made a number of times arrived in India with Muslim astronomers or astronomical instrument-makers. The information as to when and how it came to India and the extent of popularity attained by it in astronomical circles is very imperfect. As to the origin of the instrument itself, it appears to be a Greek invention —Hipparchus (150 B.C.), Apollonius (260-200 B.C.), and Eudoxus (350 B.C.) being variously credited with the knowledge of stereographic projection, the basic principle of the instrument. No less an authority than Vitruvius would have us believe that 'according to some, Eudoxus, the astronomer, invented the arachne, according to others, Apollonius' (*dicitur invenisse arachnen Eudoxus astrologus; nonnulli dicunt Apollonium*).[16] Curiously enough, the instrument is not mentioned in the *Almagest.* But Ptolemy was certainly acquainted with the instrument, for he wrote a tract on stereographic projection which was translated into Arabic in the tenth century and from Arabic into Latin in the twelfth. In the fourth century A.D. Theon of Alexandria wrote a small tract in which the term 'little astrolabe' was first used. The first full-fledged work on the astrolabe is that of Philloponus (*c.* A.D. 530). About a hundred years later Severus Sebokht produced another tract, clearly based on Theon's work.

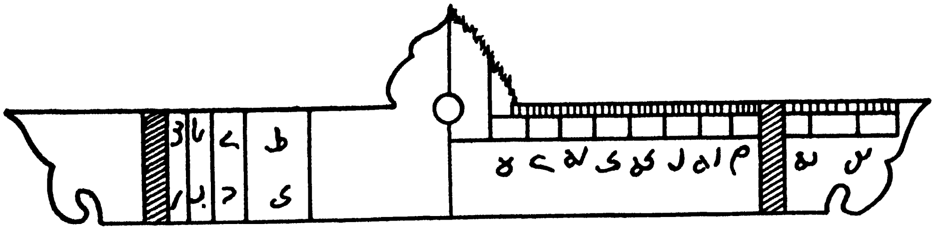
The credit of real development in astrolabe-making, however, goes to Arab astronomers and instrument-makers, starting from around the ninth century. Thus al-Fazārī (*c.* 800), one of the earliest Muslim astronomers, wrote a tract on the subject. Other notable early astronomers of Arab culture areas who wrote important tracts on the astrolabe include Abū'l-Ma'shar, Umar al-Balkhī, 'Ali ibn Isā of Baghdad, al-Farghanī (*c.* 830), al-Bīrūnī (973-1048), al-Majrīṭī of Cordova (*c.* 1000), al-Zarkali (*c.* 1029), and Nasir al-Din aṭ-Ṭusī (1201-74). Al-Bīrūnī's two tracts on the instrument, *Kitāb fī ist'iāb al-wujūh al-Mumkin fī san'at al-asṭurlāb* (Comprehensive Study on Possible Methods for the Construction of the Astrolabe) and *Kitāb al-tafhīm li-awā'il ṣinā'at al-tanjim* (The Book of Instructions in the Elements of the Art of Astrology), attained great popularity and are available in translations in European languages.[17]

[16] *De Architectura*, Book IX, Ch. 8, quoted by H. Michel in *Traité de l'astrolabe* (1947), p. 6.

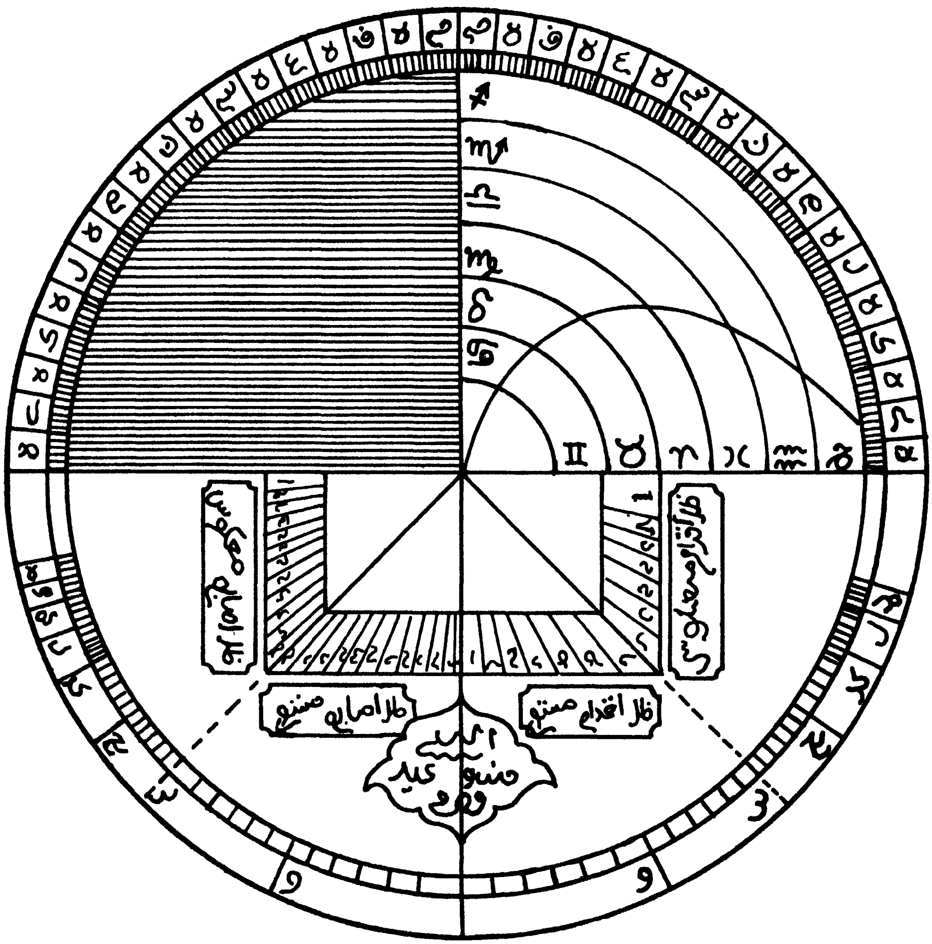
[17] E. Wiedemann, 'Einleitung zu dem Werk über die eingehende Behand lung (istilāb) aller möglichen Methoden für die Herstellung des Astrolabs', *Das Weltall*, XX (1919), pp. 24-26 (contains translation of the introductory part). The more general parts dealing with construction are dealt with by E. Wiedemann and Josef Frank in 'Allgemeine Betrachtungen von al-Bīrūnī in seinem Werk über die Astrolabien', *Sitzungsber. der Physik Medizin ... in Erlangen,* LII (1922), pp. 97-121; *Z.* für Instrumentenkunde, XLI (1921). *Al tanjīm* was translated by Ramsay R. Wright as *The Book of Instruction in the Elements of the Astrology by al-Bīrūnī Written in Ghaznal* 1029 A.D.; English translation with Arabic text (Luzac and Co., London, 1934).



ASTROLABE : FRONT SHOWING THE SPIDER WITH STAR MAP AND PLATE FOR READING THEIR COORDINATES



THE RULER OR ALIDADE



THE BACK OF THE ASTROLABE SHOWING SHADOW SCALE,
SINE GRAPH, DECLINATION CIRCLES, ETC.

Of the three main types of astrolabes, i.e. the flat or planisphaerum, spherical, and linear, the first type is the most common. Its essential parts are (i) a thick circular disc, generally of metal, of a diameter varying from 5 to 50 cm., called *mater* or 'mother' (Arabic *'umm*); (ii) a star map called 'spider', *aranea* or rete (Ar. *'ankabūt*); (iii) a number of circular plates called tablets or tympans (Ar. *ṣafīḥaḥ*); and (iv) a ruler fitted with a sighting device called dioptra or alidade (Ar. *al-'iḍāde*). All the pieces are pierced at the centre so that they can be held together with an axis or pivot (Ar. *miḥwār* or *quṭb*) and fixed by a bolt called 'horse' (Ar. *faras*). The 'mother' is a thick circular plate with a hollow space so designed that the star map and the various tablets can be exactly fitted within it. The 'mother' has a raised rim graduated in 360 degrees or in four quadrants each divided into 90 degrees. The inside surface is inscribed with place names and their latitudes and longitudes. This is usually done by drawing several concentric and radial lines, dividing the space into several groups of three, one for writing the name of the place and the other two for its latitude and longitude. The back of the 'mother' is provided with several computing devices. Some common features are a zodiacal calendar, altitude scales, a square for measuring shadows and heights, a circular cotangent scale, sine graph, and declination graph. Special tables for astrological computations are also provided.

The rete or 'spider' is the most conspicuous and at the same time ornamental part of the instrument. It looks like a spider because several areas of it are scooped out leaving a number of pointed and curved projections, each inscribed with the name of a prominent star. These projecting pieces are called *shaẓāya* in Arabic. The 'spider' is really a star map in projections and contains an ecliptic circle unequally divided into twelve parts to represent the twelve signs of the zodiac: Aries (*al-ḥamal*), Taurus (*al-thūr*), Gemini (*al-jūzā*), Cancer (*al-saraṭān*), Leo (*al-asad*), and so on. The celestial latitudes and longitudes of the stars can be easily read with the help of a special tablet called *ṣafīḥaḥ mizān al-'ankabūt* (tablet for stellar measures). Other tablets are engraved with stereographic projections of the tropics, the equator, the altitude and azimuth circles, hour lines, etc. By the skilful use of the astrolabe with its plates and various graduations, it is possible to tell time during day and night, find positions of the sun and stars, solve problems of heights and distances, make other computations, and, above all, teach the elements of astronomy.

India has a good collection of astrolabes, imported as well as locally made. Among the old astrolabes, a thirteenth-century one inscribed in Kūfic characters and *abjad* numerals is now kept in the collection of the Archaeological Museum at the Red Fort, Delhi. Gunther informs us that in the last century Professor Wilson at Benares had in his possession a thirteenth-century astrolabe con-

structed by Mahmud Ben Ali Ben Yusha Alri in 1270.[18] During the sixteenth and seventeenth centuries India produced a number of highly skilled astrolabe-makers whose instruments are to be found in this country and in various museums of the world, particularly the History of Science Museum at Oxford. A large number of them bear the names of the members of the family of Shaikh Allāh-Dād (*c.* 1570), who established his reputation as a master astrolabist in Lahore during the reign of Humāyūn.[19] Allāh-Dād's son Mullā 'Isā (*c.* 1600), flourished during the reign of Akbar. His two sons Qā'im Muḥammad (*c.* 1630) and Muḥammad Muqīm (*c.* 1640) attained great reputation during the reign of Jahangir and Shāh Jahān and left behind a number of astrolabes engraved with their names, now the prized possession of several museums. This tradition continued with distinction in the fourth generation by Allāh-Dād's great grandson Ḍīyā al-Dīn Muḥammad (*c.* 1650). During 1971-74 I carried out a survey of astrolabes in India in connection with a research scheme relating to scientific instruments of historical importance under the auspices of the Indian National Science Academy and also had the privilege of visiting and working at the Museum of History of Science in Oxford. Over thirty astrolabes were then located in India. Besides the members of the Allāh-Dād family, some other Indian astrolabists known from their engravings include Muḥammad Ṣālih of Tatta (*c.* 1660), Muḥammad Zaman al-Mumdjīm (*c.* 1660), Ibn Muḥibb Ḥaqiqah (*c.* 1653), J'afar bin 'Umral Kirmani, Muḥammad Amīn ibn Muḥammad Ṭāhir, Sayyid 'Abd al-Bāqi Sayyid Ḥusain (*c.* 1790), and Gulam Qadir of Kapurthala (*c.* 1840). Gunther has recorded eight astrolabes with Sanskrit inscriptions, some of which were described by Kaye and Morley.

When the Hindu-Arabic synthesis was thus taking place, the ancient and medieval science of astronomy had lost much of its force and value. Europeans had already arrived and started their survey and other scientific operations with much improved and more powerful instruments. In Madras and Calcutta telescopes appeared on the rooftops of houses of a few private individuals and some resourceful officials of the Company. Henceforth our attention became fixed on the scientific activities of Europe.

[18] R. T. Gunther, *The Astrolabes of the World*, Vol. I (Oxford, 1932), pp. 61-81.

[19] S. Nadvi, 'Some Indian Astrolabe Makers', *Islamic Culture*, IX (1935), pp. 621-31; and Nabia Abbott, 'Indian Astrolabe Makers', *Islamic Culture*, XI (1937), pp. 144-46.

7

PHYSICS AND MECHANICS IN ANCIENT AND MEDIEVAL INDIA

PHYSICS, mechanics, and related branches of science are of comparatively recent origin. In Europe they started taking definite shape around the end of the sixteenth and beginning of the seventeenth centruries. That does not, however, mean that the ancient world was quite barren of all kinds of thought and speculation about what later on came to be recognized as physics. Experiences of the material world, of properties or behaviour of matter, of motion, light, sound, electricity, and so on were bound to, and did, generate speculations and lead to certain efforts at systematization quite early in man's intellectual history. This is more or less true of all early civilizations, for whatever culture evinced interest in understanding man's physical environment could not fail to be intrigued by the material content of it. In the case of the ancient Indian civilization we find abundant evidence of this situation in its early literary and philosophical productions. Wondering at the eternal mystery of the creation of the universe, the authors of these works went deep into the question of the nature of matter and its behaviour and not infrequently provided answers to problems which sometimes appear refreshingly modern.

Take the question of the physical reality of matter which attracted the attention of all philosophical schools in India as elsewhere with varying degree of intensity. The Nyāya-Vaiśeṣikas approached the problem from a fixed number of physical realities, the categories, six in number and headed by *dravya* (substance). The Vaiśeṣika conception of matter is embodied in this very term which includes as criteria ability to act as a substratum of qualities, to be endowed with motion, and to provide an inherent or material cause. Substance exists in nine different types, viz. earth, water, fire, air, ether, time, space, soul, and mind. The *Vaiśeṣika-sūtra* and one of its earliest expositions, the *Padārthadharma-saṅgraha* of Praśastapāda, also known as *Praśastapāda-bhāṣya*,[1] have dealt with the problem of matter at great length, recognizing its atomic character and the role of atoms and their aggregates in various physico-chemical reactions.

Primarily concerned with the origin and evolution of matter, the Sāṁkhya system developed the concept of Prakṛti and its three *guṇas*, *sattva*, *rajas*, and *tamas*, representing respectively the essence or the intelligence stuff, the dynamic principle, and the inertia or the restrictive principle inherent in matter. The great merit of the system is its recognition of the energy principle and its conservation in the conception of matter.

Receding considerably from the realism of the Vaiśeṣikas and the exponents of the Sāṁkhya system, the Jains and Buddhists none the less speculated from

[1]Ed. Gopinath Kaviraj and Dhundiraj Sastri, Chowkhamba Sanskrit Series, 1930.

their respective metaphysical standpoints upon the nature of matter. *Pudgala*, the Jaina term for substance, is in a continuous state of flux undergoing integration and disintegration all the time, processes which are rendered possible by the atomic character of matter and the working of various inter-atomic forces. To the Buddhists matter is to be comprehended through their forms (*rūpa*) and qualities such as sound, odour, taste, touch, etc. which are responsible for the substancehood of matter. While opposed to the Vaiśeṣika concept of atoms, the Buddhists, particularly the Sarvāstivādins, believed in some kind of atomism.

MECHANICS—MOTION OF BODIES

While speculating on matter, the Vaiśeṣika realists did not fail to notice the fundamental importance of motion. In fact, one of their definitions of substance recognizes motion as an inherent quality of substance (*kriyāvattva*). Moreover, motion (*karma*) is acknowledged as one of the six categories with which to comprehend the physical world. In attempting to survey the development of concepts in physics we may do well to start with the subject of motion in which the ancient Indians made notable progress.

The basic concepts of motion were introduced during the formulation of the Vaiśeṣika aphorisms (*c.* 300 B.C.). Unfortunately, no further study of the nature of motion was undertaken by the later exponents of the school until Praśastapāda (*c.* A.D. 600) revived the ideas in his *Padārthadharma-saṅgraha*. Praśastapāda's definition of motion involves discussion of its characteristic properties. These properties, as enumerated by Sen,[2] may be stated as follows: (i) peculiarity of a single motion affecting a single body (at a time) —*ekadravyatva*; (ii) instantaneity —*kṣaṇikatva*; (iii) property of appertaining to corporeal bodies only—*mūrta-dravya-vṛttitva*; (iv) lack of qualities—*aguṇavattva*; (v) property of being generated by gravity, fluidity, volitional effort, and conjunctions—*gurutva-dravatva-prayatna-saṁyogajatva*; (vi) property of being opposed by conjunctions caused by themselves —*svakārya-saṁyoga-virodhitva*; (vii) property of acting as independent cause of conjunctions and disjunctions —*saṁyoga-vibhāga-nirapekṣakāraṇa*; (viii) property of acting as non-inherent cause —*asamavāyi-kāraṇatva*; (ix) property of initiating effects (by conjunctions and disjunctions) in their own as well as in other substrates—*svaparāśraya-samaveta-kāryārambhakatva*; (x) inability to initiate its own kind —*samāna-jātīyānārambhakatva*; (xi) inability to generate motion in other bodies —*dravyānārambhakatva*; and (xii) classificability into distinct types characterized by directions of initial motion—*pratiniyata-jātiyogitva, digviśiṣṭa-kāryārambhakatva*.

Praśastapāda defines motion as the change of place of particles as itemized in (vii). He regards motion as instantaneous (*kṣaṇika*) in its simplest form (item ii)

[2] S.N. Sen, 'The Impetus Theory of the Vaiśeṣikas', *Indian Journal of History of Science*, Vol. 1 (1966), p. 37.

distinguishing it from impressed motion, momentum (*vega*), which is a persistent tendency (*saṁskāra*) and implies a series of motions.[3] This concept does not readily correspond with Galileo's (1564-1642) concept of uniform motion in a straight line. That motion is not a mere displacement (*saṁyoga-vibhāga*) but is endowed with directional properties (*digviśiṣṭa-kāryārambhakatva*) or a vector quantity is indicated in (xii).

Although Praśastapāda was aware of the nature of vectors, he did not explore their properties. In any case, he may be considered to be a pioneer in vectorial concept. The Vaiśeṣika school also holds that when a body moves, its motion belongs to itself alone (*ekadravyatva*) and so one event of motion cannot initiate another. This postulate has been more forcefully expressed by Śrīdhara (*c.* A.D. 991) in his assertion that there can be only one event of motion in any body at a given time (*ekadā ekasmin dravye ekameva karma vartate*). Praśastapāda has described other types of motion besides rectilinear, viz. curvilinear motion (*gamana*), rotatory motion (*bhramaṇa*), and vibratory motion (*spandana*). We meet with Praśastapāda's interesting statements about the motion of falling bodies. Such motion is produced by gravity alone. This leads to an impressed motion (*saṁskāra*) in the same direction. As the force of gravity continues to operate, the motion of the falling bodies is due to gravity as well as *saṁskāra*. The resultant motion is one, but both the causes must be conceived as contributing to the resultant. According to Seal,[4] a good foundation was thus 'laid for the explanation of accelerated motion of falling bodies, but Galileo's discovery was not anticipated, as Galileo's observations and measurements of motion were wanting'. Had the Vaiśeṣikas explored the resultant motion of a vertically falling body experimentally, they would in all probability have discovered Newton's force-acceleration relationship as represented in the equation $F=ma$, where F is the force, m the mass, and a the acceleration.

Unfortunately, no instrument was available then for an accurate determination of small intervals of time. Indeed, the free fall of bodies is too fast to be studied in any detail without sophisticated modern equipment such as instruments for fast photography. It is interesting to note, however, that Galileo decided to 'dilute the force of gravity' by making a ball roll down an inclined plane. He also measured the time taken by the ball to cover different distances by means of a water clock. The time was measured by the amount of water pouring out through a little opening near the bottom of a large container.

Now, gravity is stated to be one of the causes of motion, the other causes being fluidity, volitional effort, and conjunction (*gurutva-dravatva-prayatna-saṁyogajatva*). Here conjunction means a special type of contact of which examples are impact (*abhighāta*) and impelling push (*nodana*). Being causes of motion, all these agents

[3] B. N. Seal, *The Positive Sciences of the Ancient Hindus* (Delhi, 1958), p. 129.
[4] *Ibid.*, p. 141.

can be regarded as forces. The word *gurutva* (gravity) has also been used in the sense of heaviness or weight, but there seems to be no correlation between gravity and mass of the substance as there is no correlation between any type of force and acceleration.

Uddyotakara (*c.* sixth century A.D.) states in his *Nyāyavārttika* that a heavier body falls to the ground with greater *vega* than one that is lighter. Since Uddyotakara's definition of *vega* is not clear, it is improper to identify it with velocity. For instance, if *vega* implies something like momentum his statement may be taken as objectively correct; because under identical initial conditions bodies falling freely under gravity will reach the ground with the same velocity. However, the heavier body will have greater momentum. Strangely enough, Uddyotakara holds, and Śrīdhara agrees with him, that the gravity as a whole of a body composed of particles (*avayavāḥ*) is not the same as the sum of gravities of the particles. There is a difference in amount which is, however, so small as to be imperceptible. This is a curious metaphysical speculation in the context of modern theories. The Vaiśeṣika explanation of objects is obviously qualitative, considering as it does the motion in terms of change with reference to space only. Nowhere does it take cognizance of the time factor. The general idea was that motions were caused by the qualities in the substance.

Concept of Vega: A motion has been generally conceived as a change of place in a particle, instantaneous and incapable of producing another motion. But when a motion is caused by impact (*abhighāta*) or impelling push (*nodana*) it develops a *saṁskāra* or persistent tendency to motion. This persistent tendency of a moving body to continue its motion has been called *vega*. That *vega* is a *saṁskāra* has been clearly stated by Praśastapāda. According to him, *saṁskāra* is of three types, viz. *vega*, *bhāvanā* (mental impression), and *sthitisthāpaka* (elasticity). This *vega* closely fits in with the modern concept of momentum as has been shown by Sen.[5]

The Vaiśeṣikas accept one and the same *saṁskāra* (impressed motion or momentum) lasting till the cessation of motion. Uddyotakara and other writers of the Nyāya school suppose a series of *saṁskāras*, each generating the one that succeeds it. It appears that the Nyāya view implies something approaching our modern idea of acceleration. The power of *saṁskāra* diminishes by doing work (*kāryakāraṇāt*) against counteracting forces and when the *saṁskāra* is in this way exhausted the moving body comes to rest. Thus *vega* corresponds to inertia in some respects and to momentum (impressed motion) in others. This is the nearest approach to Newton's first law of motion.

Units of Space and Time, Co-ordinates: The solar day was taken as a natural measure or division of time. In the Nyāya-Vaiśeṣika school the day of 24 hours (solar) is stated to contain 1,944,000 units of time (*kṣaṇa*). The Nyāya unit of

[5] Sen, *op. cit.*, pp. 39-41.

time therefore measures ·044 second. It may be recalled that the modern time is defined as $\frac{1}{86400}$ of a mean solar day; it is the same in the metric and English systems. The smallest measure of time used by ancient Indian astronomers is *truṭi* which is $2{\cdot}9623 \times 10^{-4}$ of a second, undoubtedly an exceedingly minute interval of time that could be conceived anywhere at that time. According to Seal,[6] the perception and its range and limits were carefully studied by the ancient Hindus. However, finer instruments of measurement were wanting and this was a principal cause of arrested progress. Indeed, their approach to the study of mechanics was by and large qualitative, being predominantly subjective without depending much on accurate measurements or experimentation.

The natural measure of length was the cubit (*hasta*) of which there were two fixed standards, the greater and the lesser cubit. It may be recalled that the early British unit of length was the foot. The smallest measure of length mentioned in Śilpaśāstra (technology) is *paramāṇu* which is about $\frac{1}{349525}$ of an inch. This is the same as *trasareṇu* of the Nyāya-Vaiśeṣika school, which stands for the thickness of the minimum visible (the finest mote perceptible in the sunbeam as it comes slanting into a dark room through a chink). According to Varāhamihira (*c.* sixth century A.D.), 8^6 *trasareṇus* when placed side by side cover up a distance which equals one *aṅguli* (about three-fourths of an inch). He also assumes that 64 *trasareṇus* equal the thickness of a filament of hair. Such inadequate methods of standardization of quantities could hardly yield quantitative results.

According to Bhāskara[7] (*c.* A.D. 1150), average velocity (*sthūlagati*) is measured in accordance with the formula $v = s/t$ where v is the average velocity, s the distance traversed, and t the time. But no unit of velocity appears to have been given. There is no clear idea of acceleration, as already stated, and of course no measurement of force. Mahāvīrācārya (*c.* A.D. 850) gives formulae for computing the space traversed in cases of *saṅkalitagati* (velocity with regular increment at stated intervals), but this does not amount to acceleration as the intervals are not indefinitely small.

Where the velocity is uniform, the interval of time may be of any amount (*sthūlakāla*), but where the velocity is variable an indefinitely small amount of time (*sūkṣmakāla*) must be taken. In other words, the positions of the particles in two successive instants must be considered and the velocity must be supposed to be uniform during this interval (conceived as indefinitely small). It is in this way that Bhāskara determines the instantaneous position of a planet. According

[6]Seal, *op. cit.*, p. 148.
[7]See Bhāskara's *Siddhānta-śiromaṇi*, *Gaṇitādhyāya*.

to Seal,[8] Bhāskara's method of determining the differential of a planet's longitude is not merely analogous to, but virtually identical with, that of the differential calculus.

In order to conceive position in space, Vācaspati Miśra (*c.* A.D. 840), in his *Nyāyasūci-nibandha*, takes three axes. The position in space of one particle relatively to another may be indicated by distances measured along three axes. This remarkable analysis by Vācaspati Miśra anticipates in a rudimentary manner the foundations of solid (co-ordinate) geometry eight centuries before Descartes (A.D. 1644).[9]

GENERAL PHYSICS

Elasticity: While dealing with *saṁskāra* as a cause of motion we have referred to elasticity, *sthitisthāpaka*, which acts upon bodies in the same way as does *vega*. All real objects suffer deformation to some extent under the action of force. The external force applied to any piece of matter, when suitably measured, is called stress. The extent of yield of the sample, when suitably measured, is called strain. Provided that the strain is not too great, it may be said for any type of deformation that strain is proportional to stress as embodied in Hooke's (1635-1703) law. This is of course the modern version.

The Vaiśeṣikas recognize elasticity as a form of *saṁskāra*. This property is assumed to reside in tangible and at the same time densely packed substances in particular. According to Śrīdhara,[10] the constituent molecules are closely packed in a dense solid substance. When such substances are deformed through displacement (of their constituent parts), this property helps them in reverting to their original position. Thus *sthitisthāpaka* is that property of a substance which restores to original form its own substratum which has been deformed. There is, therefore, no difficulty in identifying it with elasticity. However, elasticity is not only a form of *saṁskāra*, it is also a cause of motion. In the act of bending a bow, for example, by the application of impelling pull, a tendency to oppose the pull is generated and stored in the body, which becomes active as the pull is withdrawn. It not only restores the bow to its original position but also initiates a motion in much the same way as *vega* causes motion. It seems that the Vaiśeṣikas concentrated more on the second aspect of motion than on the study of the first aspect which is the basis of Hooke's law.

Properties of Fluids—Fluid Motion: A solid, besides resisting volume changes, opposes changes in shape, while shapeless fluid can resist volume changes only. According to the *Praśastapāda-bhāṣya*,[11] fluidity is considered to be the property

[8] Seal, *op. cit.*, pp. 149-50.
[9] *Ibid.*
[10] See Śrīdhara's *Nyāyakandalī* (Varanasi, 1963).
[11] Varanasi edition (1963), pp. 70-71.

of three types of substances —earth, water, and fire. It is expressed by the action of flowing as gravity is expressed by the action of falling of bodies. Fluidity is of two types: natural and incidental. The former is the specific property of water. Even so, water is said to lose this quality on solidification (in the form of snow or hail). There is even a view that the fluidity of water atoms is brought about by some external agency like subtle supernatural fire. Fire is also regarded as a substance possessing the quality of fluidity, for fluidity of melted butter or gold is caused by fire. Fluidity, as already noted, is a cause of motion.

Viscosity: The cause of cohesion and smoothness of water is attributed to viscosity (*sāndratā*). This property counteracts any tendency of the particles to disperse. Thus it is an operative cause of conjunction. According to modern ideas, viscosity resists sliding of the fluid even when finite velocities are involved. A fluid which possesses no viscosity is called a perfect fluid, an ideal state unknown in nature.

Surface Tension: The phenomenon of capillary motion (*abhisarpaṇa*) is recognized by Śaṅkara Miśra (*c*. A.D. 1500), who illustrates it in his *Upaskāra* by two examples: (i) the ascent of the sap in plants from the root to the stem, and (ii) penetrative diffusion of liquids in porous vessels. However, the cause of surface tension as being the attraction of liquid molecules at the surface by others within the bulk was unknown, and so it was ascribed to *adṛṣṭa* (lit. unseen cause) which cannot be ascertained by either observation or inference including hypothesis.[12]

Evaporation: In evaporation (*ārohaṇa*), the fluid particles are dispersed and they remain in a fine state of suspension. The dispersion is due to the impelling push (*nodana*) or impact (*abhighāta*) of the heat particles in the sun's rays and the upward movement is due to this impulse or impact in contact with the air. Śaṅkara Miśra[13] notes that in the process of boiling there is a similar upward movement of water particles under the impact of heat corpuscles (*tejaḥ-paramāṇu*). The formation of clouds in the upper atmosphere due to the condensation of water vapour escaping from the surface of seas and oceans through evaporation by the sun's heat and subsequent production of rain are mentioned in Vedic literature.

Hydrostatics: Ancient Indians appear to be silent about the principle of Archimedes (*c*. third century B.C.). In his *Nyāya-līlāvatī*, Vallabhācārya (*c*.A.D. 1200) speaks of a peculiar resistance (or gravity) offered by water to a sinking body. This may explain the tendency in certain objects to float or come up to the surface of water, but the description does not reflect any awareness of

[12] Śrīdhara, *op. cit.*
[13] Śaṅkara Miśra's comments in *Upaskāra* on *Vaiśeṣika-sūtra*, V. 2. 5-6.

Archimedes' principle, namely, that a body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid.

HEAT

According to the *Ṛg-Veda* (VI. 16), Atharvan, also known as Aṅgiras, was the first discoverer of fire. It is interesting to note that the term *aṅgāra* (charcoal) has a striking resemblance to the name Aṅgiras. Atharvan's fire was first harnessed by Viśvāmitra who devised a mechanical method of producing fire by friction (III.29). Although the production of fire by the friction of two sticks was well known during the Vedic period, succeeding generations did not trace the link between the apparent disappearance of mechanical energy and its appearance in the form of heat as formulated in Joule's law.

It is true that Praśastapāda conceived of molecular (atomic) motions (*parispanda*) which involved whirling or rotatory motion, a circling motion, and also simple harmonic motion (e.g. vibration). It was also realized that all action or operation or work (*kriyā, vyāpāra*) is ultimately traced to this form of subtile motion lodged in the atoms or in the matter stuff. The Nyāya-Vaiśeṣika school postulates that motion (*parispanda*) is present in all forms of matter except *ākāśa* which is regarded as non-atomic, not subject to any change, and incapable of any activity (*niṣkriya*). In fact, all atoms are in a state of incessant motion. According to Raghunātha Śiromaṇi (*c.* fifteenth century A.D.), the world at bottom is an infinitude of continuously whirling or vibrating particles. This hypothesis anticipates the kinetic theory of matter developed in the nineteenth century. But the equivalence of mechanical energy and heat was not realized. In his *Upaskāra*, Śaṅkara Miśra elaborately discusses the various properties of heat. During his time, however, there was no scientific instrument for its measurement. The first really scientific instrument for temperature measurement was invented in 1592 by Galileo.

The function of heat in chemical combinations is recognized by Vātsyāyana (*c.* fourth century A.D.).[14] In the case of combustion, Vijñānabhikṣu (seventeenth century A.D.) explains heat as latent in the earth substance, the fuel from which it breaks forth. Udayana (*c.* tenth-eleventh century A.D.) points out that solar heat is the source of all stores of heat required for chemical change in the world.

Physico-chemical Changes through the Action of Heat: It was well known from quite early times that physico-chemical changes were generally brought about by the application of heat. The Vaiśeṣika and Nyāya schools considered some of these problems in considerable detail and attempted to explain such changes on the basis of their favourite theory of the atomic constitution of matter. About the atomic constitution, Praśastapāda had already argued that *tryaṇukas* and higher aggregates were formed out of diads. These molecular

[14] *Vātsyāyana-bhāṣya*, IV. 1. 47.

groupings may be densely or loosely packed leading to molecular groupings or collocations (*vyūhas*) which are profoundly affected by the action of heat producing various kinds of chemical changes. This heat is sometimes called the *taijasa* element, atomic in structure. The process of physico-chemical change by the action of heat particles is described in the Nyāya-Vaiśeṣika literature as *pāka*, and depending upon the mode of action, two theories, viz. *pīlupākavāda* and *piṭharapākavāda*, have been propounded.

The baking of an earthen pot is a commonplace experience. During the process not only is the plastic pot hardened into a solid and strong pot, but it undergoes at the same time a colour change. How do all these changes take place? The Vaiśeṣikas explain that the fire particles at first strike the pot with forces already noted as *abhighāta* and *nodana*, disturb their molecular groupings, and eventually reduce them into atoms. Further action of the fire particles upon the atoms brings about a transformation of the colour from the original black into red. In the third stage, a further set of heat particles brings about conjunction of the newly transformed atoms leading to the formation of diads, triads, and higher aggregates. The whole theory is called *pīlupākavāda* from the action of fire particles on isolated atoms or *pīlus*

Here the Naiyāyikas raised an objection. If the heat particles are to react upon isolated atoms for the colour change and the first set of heat particles is to reduce the molecular aggregates into atoms, the whole earthen pot should disintegrate into an atomic state and disappear from the view, which is, however, not the experience of the potter. For if one were to keep a watch through a hole on the pot within the furnace, the pot would be found to retain its shape throughout the heating operation. So they advocated a somewhat modified theory maintaining that the fire particles entering the pot through its numerous minute pores carried out the processes of atomic disjunctions and conjunctions throughout the pot as a whole. This is called *piṭharapākavāda*, that is, the theory of thermal action on the body as a whole.

LIGHT

The nature and properties of light and its interactions with material bodies obviously attracted the attention of ancient Indian philosophers. Gautama introduced the subject in his *Nyāya-sūtra*[15] in order to discuss the physical nature of light and its impact upon visual organs. It is postulated that light rays emanate from the eye and get into contact with objects, large or small, even as there is contact between light rays (emanating from a burning lamp) and the object on which they are incident. This conception seemed to derive its support from the prevailing belief that light rays appear to emanate from the eyes of 'night walkers' like cats and other feline animals.

[15] *Ibid.*, III. 1. 38-70.

The subject was further elaborated in the *Vātsyāyana-bhāṣya*. According to the Nyāya-Vaiśeṣika school, the *tejas* (light) of the burning wick of a lamp gradually spreads in increasing circles and illuminates the objects of various sizes; similarly the *tejas* from the eye goes out and spreads in wider circles apprehending the objects of different sizes. It is held by the Mīmāṁsaka school[16] that vision, like light, goes on expanding gradually, its range depending upon the extent of the stretch. The extent of the stretch itself is said to terminate at the object, perhaps encompassing it.

The Mīmāṁsakas also think that the flame is the collection of a large quantity of light particles (photons) at the burning zone of the wick. These corpuscles are believed to be in high motion and constitute a sort of radiation diffused by the flame and proceeding away from the burning wick. According to Uddyotakara,[17] a ray of light is supposed to imply the rectilinear propagation of indefinitely minute particles in all directions with inconceivably large velocity and a sort of conical dispersion. On the other hand, Cakrapāṇi points out that light waves travel in all directions like sound waves but with higher speed.

Thus light was supposed to consist of small corpuscles shooting out from the luminous body with high speed and also considered as waves of radiation spreading out from the luminous source through some medium believed to permeate all space. Today we have a sort of combination of these two ideas with subtly varying interpretations.

Reflection of light has been explained by Varāhamihira as being due to the impingement of light corpuscles on the atoms of a suitable material and the subsequent back-scattering (*kiraṇavighaṭṭana, mūrcchana*). Vātsyāyana calls it *raśmiparāvartana*. This hypothesis has been suitably modified to explain degrees of opacity, the property of casting shadows, etc. However, Suśruta (*c.* first century A.D.) was already aware of the fact that the ray which impinges upon the retina serves the double purpose of illuminating the eye and the external world, and is in itself converted into the sensation of sight.

On the other hand, refraction is explained as being due to the penetration of light rays or corpuscles through inter-atomic spaces of a translucent or transparent (*svaccha*) material. Uddyotakara calls it *tiryaggamana* (deflection or refraction) and compares it with *parispanda*, the phenomenon of fluids penetrating the porous bodies (*tatra parispandaḥ tiryaggamanaṁ parisravaḥ pāta iti*). It is doubtful whether the laws of reflection and refraction of light were really known.

The ability to perceive and recognize colour is a characteristic feature of human vision. The perception of colour was stated to be due to the presence of several components (dispersion) and also the basic character of colour

[16]Kumārila Bhaṭṭa's *Ślokavārttika*, trans. G.N. Jha (Bibliotheka Indica Series, 1909), IV. 47-48.
[17]Uddyotakara's commentary on Vātsyāyana's *Parispanda-parisravau*, III. 1. 47.

itself. Thus light, in general, was stated to possess diverse characteristics as given below:

(i) Both colour and touch are perceived. The sun's rays are simultaneously perceived by the eye and felt by the skin.
(ii) Colour is manifested while touch is not, just as light from the lamp or moon is seen by the eye only but not detected by the skin.
(iii) Touch is manifested and colour is not, as in the case of water heated by sunlight.
(iv) Both colour and touch are unmanifested in the case of the rays from the eye itself.

It appears, therefore, that the phenomenon of dispersion or the true concept of colour was not understood in its proper perspective. Incidentally, the mysterious sensation of colour by our visual organ is still a very much controversial subject as has been pointed out by Raman.[18] Of particular interest are the different ancient views about the characteristics of the visual sense-organ itself. The Nyāya-Vaiśeṣika school[19] holds that the eyes are constituted mainly from the ultimate particles of *tejas* as determined by *adṛṣṭa* so that they can comprehend colour. According to the Buddhists, however, the eye-balls physiologically represent the visual organs. These eye-balls are material bodies which can perceive external objects through the agency of external light beams. They did not subscribe to the idea of light beams emanating from visual organs and falling on objects situated at a distance.

SOUND

Ancient Indian thinkers held different views about the origin and propagation of sound. Followers of the Mīmāṁsaka school held that the physical basis of sound was a series of air movements (*vāyusantāna*). According to Uddyotakara and Vācaspati Miśra, air particles flow in a current in all directions and are obstructed in their path by the impact of material bodies; eventually the movement ceases as it does in the case of an arrow when the moving force is exhausted. Śabarasvāmin (*c.* fifth century A.D.),[20] however, thinks that sound is a wave motion in air, being the transmission of conjunctions and disjunctions in the minute particles of air, the wave originating in the first impact and being continued by the successive impacts of minute particles. According to this view, the particles of air are subject to a vibratory motion, a sort of *parispanda*, in the production of sound.[21]

Early Nyāya writers held that the sound wave had its substratum in *ākāśa*

[18] C. V. Raman, *The Physiology of Vision* (Indian Academy of Science, Bangalore, 1968).
[19] Seal, *op. cit.*, pp. 115-17.
[20] *Śabarabhāṣya*, I. 1. 13.
[21] See *Nyāyamañjarī* of Jayanta.

(ether) and not in *vāyu* (air). Later writers (e.g. Vācaspati Miśra) added that sound itself as a phenomenon was not to be conceived as a mode of motion, for *ākāśa* was incapable of motion. Praśastapāda's hypothesis was that sound at any moment formed a circle in *ākāśa* and the propagation of sound was carried on in the air by means of ever-expanding circles as in the case of waves in water. The Mīmāṁsakas, on the other hand, explained the physical aspect of sound and the mode of its propagation as being due to condensation and rarefaction of air molecules. This was also the view of Bhartṛhari. In his *Tattva-cintāmaṇi*, Gaṅgeśa (fourteenth century A.D.) explains the velocity of sound on the basis of movements of air waves, vehicles of sound.

Echo (*pratidhvani*) was supposed to be a reflection of sound in the same way as an image in water or in a mirror is due to the reflection of light.

Pitch, Intensity, and Timbre: Sounds differ from one another (*tāramandādibheda*) by intensity (*tīvramandādibheda*) and quality or timbre (*asādhāraṇa-dharma*). The differences in pitch (tones and overtones) as well as in intensity were ascribed to the variations in *saṁskāra* (momentum, *vega*) of the vibrations (*kampasantāna-saṁskāra*) of molecules swinging to and fro and becoming feebler and feebler.

Sounds also differ from one another in volume in the case of coalescence (*samāna-jātīyopacaya*) or synchronization of phase. Śabarasvāmin explains volume (*mahattva*) as due to *nādavṛddhi*, the coalescence of different air waves affecting a larger tract of ear-drum.

Musical Sounds: The distinguishable pitches were called *śrutis*. These were believed to be associated with momentum (*vega*) and frequency of vibration (*kampanasaṁkhyā*). The ratio of a note to its octave (in respect of pitch) was given as 1:2. An indefinite number of *śrutis* could be interposed between a note and its octave. Twenty-two such *śrutis* were named and recognized for musical purposes. A *śruti* was conceived as a simple (unmixed) and fundamental tone of a certain pitch whereas an ordinary musical tone (*svara*) is really composed of a fundamental tone (*śruti*) and certain partial tones (harmonics, *anuraṇana*).[22] The relation between a *śruti* and a *svara* is variously conceived as: (i) nodal change (*pariṇāma*), (ii) manifestation (*vyañjana*), (iii) relation of genus and species (*tādātmyaṁ jātivyaktyoriva*), (iv) reflection (*vivartana*), and (v) relation of cause and effect (*kāryakāraṇabhāva*).[23]

The musical tones are related to one another in four ways. The explanation of these in terms of melody and harmony is altogether unknown in medieval compilations. On the other hand, modern western music cultivates mostly harmony. It was Helmholtz (1821-94) who found that only sources giving a number of well-developed harmonics are musically pleasant. He also pointed

[22] Dāmodara's *Saṅgīta-darpaṇa*, I. 49.
[23] Seal, *op. cit.*, p. 166.

out that, mathematically, the consonant intervals are those which give coincidences among these harmonic overtones. While Indians concentrated on melody, i.e. pleasing succession of notes, western musicians cultivated harmony, i.e. pleasing combination of notes.

MAGNETISM

The discovery of magnetism is attributed to the Greek philosopher Thales of Miletus (640-546 B.C.). But the polarity of magnets and also repulsion between like magnetic poles were unknown to the ancient Greeks. There is hardly any reference to the study of magnetic phenomena by ancient Indian philosophers. However, Śaṅkara Miśra notes the movement of an iron needle towards a magnet and discusses in his *Upaskāra* the preparation of magnets by the process of rubbing (*sammārjana*) and the placing of magnets right along the magnetic poles (*ṛjusthāpana*). Bhoja's *Yuktikalpataru* (*c.* A.D. 1100) advises shipbuilders against using iron in holding or joining together the wooden planks of the bottoms of sea-going vessels, for the iron would expose them to the influence of magnetic rocks in the sea. However, there is no clear mention of a magnetic needle in early Indian literature.

ELECTRICITY

Śaṅkara Miśra in his *Upaskāra* (V.1.15) notes that amber attracts grass, straw, etc. Evidently, this is an example of electrostatic attraction. But, as in the case of magnetic attraction of iron, this phenomenon was attributed to *adṛṣṭa* and was considered to be an example of unexplained motion in matter. William Gilbert (1540-1603), an Englishman, was the first to use the terms 'electric force' and 'electric attraction'.

MACHINES AND MECHANICAL CONTRIVANCES

Ancient Indians devised many contrivances for obtaining mechanical advantage. Mechanical advantage makes it possible to obtain a large force by the application of a small one, although the work done by both the forces is the same. We have already noted that the first fire was produced by Atharvan by mechanical means. Viśvāmitra first harnessed fire by devising an apparatus of attrition. The *Ṛg-Veda* (III.29) mentions *ādimanthana* as an apparatus of attrition consisting of a stick and a string placed upon two pieces of wood. *Prajanana* is described as the general method of producing fire. The *Śatapatha Brāhmaṇa* refers to chariot races. Many mechanical devices and implements of Vedic times connected with grinding and pounding corn, macerating it with water, squeezing out its juices and extracts through various types of strainers, etc. have been catalogued by Satya Prakash.[24] A large variety of war

[24]Satya Prakash, *Founders of Sciences in Ancient India* (Research Institute of Ancient Scientific Studies, New Delhi), p. 53.

weapons and mechanical contrivances for hurling projectiles against the enemy have been described in Kauṭilya's *Arthaśāstra* (c. 300 B.C.). In the *Yuktikalpataru* diverse subjects of secular interest such as construction of buildings, selection of sites for the same, and making of articles of furniture are discussed. The same text gives elaborate directions for decorating and furnishing ships so as to make them comfortable to passengers.

Several types of machines have been referred to in the *Samarāṅgaṇa-sūtradhāra* (c. A.D. 1100) of Bhoja. Perhaps the most fundamental technical development is the description of chronometers or time-indicating devices. It may be noted that Galileo tried and failed to discover the means of finding longitude at sea because he had no accurate time-measuring instrument. Hooke and Huygens (1629-95) had this in mind in their attempts to improve the performance of existing clocks. Indeed, the first pendulum clock was invented by Huygens during the middle of the seventeenth century. And so it is rather surprising to find descriptions of mechanical time-measuring instruments like chronometers (*putrikā-nāḍīprabodhana*) with periodic chiming devices in the *Samarāṅgaṇa-sūtradhāra*. Many other mechanical devices like wooden robots, astronomical models of heavenly bodies in motion, vehicular contrivances, and water supply plants have been described in detail in the same text.

8

BOTANY IN ANCIENT AND MEDIEVAL INDIA

THE study of plant life or botany in India can be traced to very ancient times. Dependence on plants for food and shelter drew pre-Vedic Indians to this study. In addition, plants were intimately connected with trade and commerce. The Indus valley civilization had commercial intercourse with West Asia, East Africa, and other centres of civilization. Most of the commodities involved in that trade were plant products, and even the transport vessels were made of wood. This necessitated a scientific study of plants and plant life.

Agriculture was the primary occupation of the people during the Vedic period (*c.* 1500-600 B.C.). As their knowledge and technology in such diversified fields as medicine, trade, and civic affairs increased, so did the scope and application of their knowledge of plants and plant life. There are indications that agriculture, medicine, and arbori-horticulture developed to a great extent during the Vedic period. Even at this early stage, knowledge of descriptive botany and rudimentary plant physiology became necessary for the successful cultivation and propagation of plants. We find in Vedic literature a large number of terms used to describe plants and their parts, including their external features and internal structures. A definite attempt at the classification of plants was also made. There is evidence that manuring and rotation of crops were practised for the improvement of soil fertility and plant nourishment. There is even indication in the hymns of the *Ṛg-Veda* that contemporary Indians had some knowledge of the process of preparation and absorption of food by plants through the action of light, and that of the storage of energy in the body of plants.

References in post-Vedic literature show that the sciences of medicine, agriculture, arbori-horticulture, and sylviculture were greatly developed in India during this period. The science of botany on which all these sciences were based must have undergone a corresponding development. This science was called Vṛkṣāyurveda, the knowledge of tree life, or Bheṣajavidyā, the knowledge of medicine, as the major portion of the medicinal substances came from plants. Both these terms occur in ancient Sanskrit texts like the *Agni Purāṇa* and *Bṛhat-saṁhitā*. In Kauṭilya's *Arthaśāstra* we get the term *gulmavṛkṣāyurveda*, and in the *Dhanvantari-nighaṇṭu* the term *bheṣajavidyā*. The *gulmavṛkṣāyurvedajña* or applied botanist, according to the *Arthaśāstra*, *Agni Purāṇa*, *Bṛhat-saṁhitā*, and other Sanskrit texts, had to know the arts of seed collection and selection, soil selection, sowing, seed germination, propagation such as grafting and cutting, planting, nursing, manuring, crop rotation, cultivation

under favourable meteorological conditions, plant treatment, plant classification and identification, landscaping, and so on. As an illustration, we may cite the test to which Bhikṣu Ātreya, the celebrated teacher of medicine at the university of Taxila, put his equally celebrated pupil Jīvaka, later physician of Bimbisāra. In the course of the examination, he was asked to seek a *yojana* on either side of Taxila and bring whatever plant he could see which was not medicinal. Jīvaka could not discover any plant which did not have medicinal properties. When he reported this to his teacher, he was declared successful.[1] Thus it is apparent that botany in India has been a continually developing science since ancient times.

No systematic work on Vṛkṣāyurveda or Bheṣajavidyā belonging to the early period is extant now. There are, however, scattered references on this subject throughout Vedic, Sanskrit, and Pali literatures from which it is possible to partially reconstruct an account of this science. This material, culled from various sources, has been arranged according to modern botanical terminology in the following order in the section covering the Vedic period: (i) classification and morphology, (ii) anatomy, (iii) physiology, and (iv) evolution.

VEDIC PERIOD[2]

Classification and Morphology: The *Ṛg-Veda* (I.164.20, 22; X.97; I.67.9) divides plants roughly into three broad classes, namely, *vṛkṣa* (tree), *oṣadhi* (herb useful to man), and *vīrudh* (minor herb). According to another classification based on their form of growth, plants are divided into *vṛkṣa* and *druma* (tree), *viśākha* (shrub with spreading branches), *sasa* (herb), *aṁśumālin* (spreading or deliquescent plant), *stambinī* (bushy plant), *vratatī* (climber), *pratanvatī* (creeper), and *alasālā* (creeper spreading on the ground). The *Atharva-Veda* (VIII.7.4) divides *sasa* further into *prastṛṇatī* (expanding), *ekaśuṅga* (one-sheathed or spathed), *aṁśumatī* (having many stalks or branches), and *kāṇḍinī* (jointed).

Different parts of a plant body are mentioned in the *Ṛg-Veda* at many places. The *Atharva-Veda* (VIII.7.12) gives an almost complete enumeration of these parts in a hymn which says: 'Rich in sweets the roots, rich in sweets the tips of them, rich in sweets the middle of the plants (stem); rich in sweets the leaves, rich in sweets the flowers of them.' Again (XII.1.27), 'Rich in flowers, rich in shoots, rich in fruits, also those lacking fruits....'

More complete and systematic accounts of the parts of a plant are found in the *Taittirīya Saṁhitā* (VII.3.19.1; 20.1) and *Vājasaneyi Saṁhitā* (XXII.28),

[1]See *History and Culture of the Indian People*, Vol. II, ed. R. C. Majumdar (Bombay, 1980), p. 580, n. 1.

[2]In the compilation of this section of my article I have drawn largely from the *Vedic Index of Names and Subjects*, 2 Vols. (London, 1912) by Macdonell and Keith. I gratefully acknowledge my indebtedness to the authors.

according to which plants comprise *mūla* (root), *tūla* (shoot), *kāṇḍa* (stem), *valśa* (twig), *puṣpa* (flower), and *phala* (fruit), while trees have in addition, *skandha* (corona), *śākhā* (branch), and *parṇa* (leaf).[3]

Descriptive terms for the various parts of a tree or plant, its texture and colour, fruits and flowers, etc. are also found in Vedic texts. The trunk of a tree is called *kāṇḍa*; plants having trunks are called *kāṇḍinaḥ*; and the term *śata-kāṇḍa* is used in describing *darbha* grass. *Śākhā* is the branch of a tree, *skandha* the corona, and *stūpa* the crest or crown over the trunk. *Valśa* is the twig of a plant; the terms *śatavalśa* and *sahasravalśa* are used to describe plants with many twigs. *Śikhaṇḍin* indicates a crested tree such as the *aśvattha* or *nyagrodha*. A plant having a hairy stem is described as *lomaśa-vasana*; one of golden colour *hiraṇya-varṇa*; a tawny one, *hari*; a ruddy one, *aruṇa*; and a brown one, *babhru*. Plants with thorns are described as *kaṇṭakinaḥ*. The leaf is called *parṇa*; a many-leafed plant is called *sahasra-parṇa*; and a plant with spotted leaf, *citraparṇī*. A leafless plant is called *karīra*. The root is called *mūla*; a fibrous root of *darbha* and other grass is called *bhūrimūla*; and a hanging root of banyan and other trees, *vayā*. *Śālūka* is the edible root of the lotus plant, and *bisa* is the lotus root fibre. The flower is called *puṣpa*; a blossoming plant is called *puṣpavatī*; and the term *prasūvarī* is used in describing a plant with fragrant flowers. *Stamba* means a bunch or cluster of grass. Fruit in general is called *phala*; and the fruit of a tree, *vṛkṣya*. Some special terms are also used to describe particular types of fruit, such as *pippala* or *pippalī* for berry and *urvāru* for cucumber. A fruit-bearing plant is called *phalinī* or *phalavatī*. The seed is described as *bīja*, such as *dhānya-bīja*. The terms *dhāna*, *dhānya*, and *sasya* are all used for grains. The *Bṛhadāraṇyaka Upaniṣad* (VI.3.13) enumerates ten cultivated grains (*grāmyāṇi*): *vrīhi* (rice), *yava* (barley), *tila* (sesamum), *māṣa* (bean), *aṇu* (millet), *priyaṅgu* (panic seed), *masūra* (lentil), *godhūma* (wheat), *khalva* (pulse), and *khalakula* (vetch).

Vedic Indians sometimes named areas according to the particular kinds of plants which thrived there. Thus in the *Vājasaneyi Saṁhitā* (XXX.16) and *Taittirīya Brāhmaṇa* (III.4.12.1) the term *naḍvala* (bed of reeds) is used in the description of a locality abounding with that species. Similarly, in the *Ṣaḍviṁśa Brāhmaṇa* (III.1) a place overgrown with *śipāla* (*Blyxa octandra*) is named as Śīpālya.[4]

Anatomy: Detailed study of the anatomy of plants was not possible in the Vedic period due to lack of instrumental facilities. The study of their gross structure and features, however, advanced to a considerable extent. In the *Ṛg-Veda* (VI.3.4), the wood of a tree (*dāru*) is distinguished from its softer outer

[3]See also *Taittirīya Saṁhitā*, VII.30.20.1; *Ṛg-Veda*, I.32.5; and *Atharva-Veda*, X.7.38.
[4]See also *Atharva-Veda*, VI.12.3.

part. The *Taittirīya Saṁhitā* (II.5.3.5 *et seq.*) considers the bark of a tree to consist of two parts, the outer (*valka*) and the inner (*vakala*). The *Bṛhadāraṇyaka Upaniṣad* (III.9.28) compares a tree to the human body and speaks of its leaves as hair; the outer bark as the skin; the sap as blood; the inner bark as the flesh; the innermost layer of bark as the nerves; its wood as the bones; and its pith as the marrow. The internal structure of a stem comprises the outer skin (epidermis and dry bark) and inner wood between which stands a soft tissue, the bast (inner and outer) and its fibres. The wood encloses the soft pith. This is indeed a far more detailed description than what we get in Theophrastus, who is regarded as the father of plant anatomy.

Physiology: It appears that the Vedic people had some knowledge of the preparation and absorption of food by plants and of the role played by light in this regard. They were aware of the phenomenon of storage of energy in the body of plants and also knew that plants draw nourishment from manure like cowdung (*karīṣa, śakṛt*).[5] According to the *Taittirīya Saṁhitā* (V.1.7.3), they practised rotation of crops by fallowing the land and by sowing different crops alternately in the same field. Roxburgh believes that for the latter practice the western world is indebted to India.[6]

Evolution: Vedic thinkers believed that plants had preceded animals, particularly man, in the process of evolution. This is indicated clearly in a hymn of the *Ṛg-Veda* (X.97.1). In the *Taittirīya Upaniṣad* (II.1), this idea of evolution is suggested by the following passage: 'From that very Ātman ether came to be; from ether air, from air fire, from fire water, from water the earth, from the earth herbs, from herbs food, and from food the person came into existence.' Similar ideas also occur in the *Chāndogya Upaniṣad* (I.1.2) and the *Bṛhadāraṇyaka Upaniṣad* (VI.4.1).

POST-VEDIC PERIOD

The study of botany made further progress in the post-Vedic period (*c.* 600 B.C.-A.D. 600). Indian literature of this period bears ample evidence of the post-Vedic people's knowledge of the morphology (both external and internal), physiology, ecology, taxonomy, etc. of plants. The *Caraka-saṁhitā* (I.1.122), for instance, observes that only a person who is well acquainted with the names and external features of plants and able to utilize this knowledge is to be called an expert physician. The *Amarakoṣa*, it may be mentioned, has a chapter on plants which enumerates more than three hundred species.

Morphology: Turning to morphology, we find that the *Suśruta-saṁhitā*

[5] *Ṛg-Veda*, II.1.14; VIII.43.9; I.161.10. See also *Atharva-Veda*, III.14.3.4; XIX.31.3; and *Taittirīya Saṁhitā*, VII.1.19.3.

[6] See G. P. Majumdar, *Upavana-vinoda* (Calcutta, 1935), p. 115.

(III.2.33) mentions that *ṛtu* (proper season, i.e. suitable temperature), *kṣetra* (good soil), and *ambu* (water) are prerequisite conditions for the germination of seeds. Guṇaratna's commentary on the *Ṣaḍdarśana-samuccaya* further mentions that the seeds of banyan, *aśvattha*, and *nimba* sprout during the rainy season under the influence of water and air. Thus it is clear that post-Vedic Indians knew that air, warmth, and water are necessary for germination. The term *uttānapāda* used in connection with germination is also significant as it is the *pāda* or root that is seen to come out first in the process of germination. Post-Vedic literature gives detailed descriptions of the parts of a plant as it grows. An instructive description of the importance of the various parts of a plant is given by Śukrācārya in his *Śukranīti* (V.24-26) where the king is compared to the root of a tree, the counsellors to stems or trunks, the commanders to branches, the troops to leaves and flowers, the subjects to fruits, and the land to the seed. The *Mahābhārata* (I.1.65-66) also contains an analogy which refers to the various parts of a tree including the trunk, branches, nodes, leaves, flowers, fruits, and seeds. The *Viṣṇu Purāṇa* (II.7.37-39) classifies the principal parts of a plant into *mūla* or *pāda* (the subterranean part) and *tūla* or *vistāra* (subaerial part). That *mūla* is the most important part of the rooted plant is noted in the *Śukranīti* (V.22-23), which speaks of a tree withering away when its roots decay. The use of the word *pādapa* (drinker of *rasa* or fluid from the soil by roots) for plants shows that the real function of the root was known. Besides *mūla*, the primary root, various other kinds of adventitious roots are referred to; for instance, *śākhā-śiphā*, *śiphā*, or *jaṭā*. Bulbous roots are mentioned in the *Arthaśāstra* (II.24). Thus the terms used to describe the diverse kinds of roots are suggestive of the knowledge of their functions.

Tūla or *vistāra* comprises two parts, namely, *kāṇḍa* (stem or axis) and *parṇa* (leaf). The former may be with *parva* (internode) or with *granthi* or *parvasandhi* (node) from which the leaf springs. Plants may be *sakāṇḍa* (with stem) as also *aprakāṇḍa* or *stamba* (without stem). A branchless stem or caudex is called *sthāṇu* or *śaṅku*. A bushy plant is described as *kṣupa*. *Śākhā*, *pratiśākhā*, and *anuśākhā* are terms used for branches in descending orders. *Kanda* is the name for an underground stem which looks like the root, though it is not really so. It is, rather, a means of propagation. *Āluka* (yam, potato) and *laśuna* (garlic) are two examples of *kanda*. The bud is called *pravāla*.

Parṇa or *patra* may be *savṛnta* (petiolate) or *avṛntaka* (sessile). A leaf, again, may be *ekapatra* (simple, unifoliate), *dvipatra*, *tripatra*, or *saptaparṇa*, and so on, according to the number of its leaflets. The shape of the leaf is also distinguished as appears from such terms as *aśvaparṇaka* (like the ear of a horse), *mūṣikaparṇī* (resembling the ear of a mouse), *kiśaparṇa* (like a monkey's ear), and *haṁsapadī* (like the foot of a duck).

Puṣpa, *prasūna*, and *sumanas* are terms used to indicate flowers. An un-

opened flower bud is called *kalikā* or *koraka*; an opened flower bud, *mukula* or *kuṭmala*; and a full-blown flower, *vikaca* or *sphuṭa*. A bunch of flowers, if cymose, is called *stavaka* or *gucchaka*, and if racemose is called *mañjarī*. Some particular types of inflorescence are called *śrīhastinī* (helicoid) and *chatrāka* (umbel). The flower stalk is called *prasava-bandhana*, that is, that which binds flowers and fruits to the mother-plant. Floral members are called *puṣpacchada* (sepal), *puṣpadala* (petal), *keśara* (stamen), and *parāga* or *keśara-reṇu* (pollen). The last two terms at once show that pollen is dust-like and is carried far. It seems that the gynaeceum had not yet been recognized, as no suitable term differentiating this organ from the male androecium is found in the literature of this period.

Phala (literally, the result of a previous process) is the term for fruit. A green fruit is called *śalāṭu*; a fleshy fruit, *jālaka* or *kṣīraka*; a dry one, *vāna*; and a legume, *śimbī*. Fruits are also named individually, such as *āmra* (mango), *jambu* (a kind of berry), *aiṅguda* (fruit of the *iṅgudī* tree), and *vaiṇava* (that of bamboo). The components of the *bīja* (seed) from which the plant germinates are described. The seed-coat is called *bījakoṣa*; the kernel or endosperm, *śasya*; and the cotyledon, *bījapatra* or *bījadala*.

Different kinds of plants are referred to. The creeper is called *latā*, *vallī*, or *vratati*. Creepers are of two kinds: those that climb upward and those that spread along the ground. They are further classed as *vallī*, a type which twines round a stem or support; *vṛkṣāruha*, i.e. epiphyte; and *vṛkṣādinī*, i.e. parasite. Algae and mushrooms are recognized as plants and are respectively called *jalanīlī* and *chatrāka*. Moss is called *śaivāla*.

Indians of the post-Vedic period distinguished five regions in the body of a plant, namely, *tvac* (skin), *māṁsa* (soft tissues or bast), *asthi* (wood or bone), *majjā* (pith), and *snāyu* (fibre in the bast). The healing up of wounds by natural recuperation is mentioned in Śaṅkara Miśra's *Upaskāra* (IV.2.5) and in Guṇaratna's commentary on the *Śukranīti*.

Physiology: That plants absorb food from the soil in a state of solution was known, as the name *pādapa* for plants suggests. The greatest achievement of the ancient Indians in the field of botany was the discovery of the phenomenon of absorption, transport, and preparation of food in the leaves in the presence of solar energy and air. This process of photosynthesis is described in two stanzas of the *Mahābhārata* (XII.177.16, 18) as follows:

> 'Just as water may be drawn up by sucking through the lotus petiole applied to the mouth, so also plants (with roots) drink (absorb and draw up the stem) water (watery solution) with the help of air.'
>
> 'With the help of *agni* (solar energy) and air (CO_2) this water (soil sap which is absorbed through the roots and conveyed to the leaves) is digested

(i.e. prepared into food proper). And it is on account of the assimilation of this food that plants attain development and become graceful.'[7]

Thus what Stephen Hales demonstrated in A.D. 1727 seems to have been known to post-Vedic Indians.

The phenomenon of the circulation of sap was discovered by Harvey in the seventeenth century. But Kaṇāda discussed it in his *Vaiśeṣika-sūtra* long before the Christian era. Much later Śaṅkara Miśra (*c.* A.D. 1500) noted it in his *Upaskāra*, which says: 'Water poured at the roots goes up in all directions through the interior of a tree. Neither impulse, nor impact, nor the sun's rays prevail there. How then is it caused?' The phenomena of osmosis and diffusion were not known to them. Hence we find them explaining it thus: 'The action by which water rises and causes the growth of the tree results from destiny (of the soul born as the tree) as its efficient cause, and water as its coherent cause.'[8] The exudation of sap (*rasasruti*), again, has been clearly described in the *Rājanighaṇṭu*. The phenomenon of phosphorescence in plants was also noticed. This has been mentioned in Kālidāsa's *Kumārasambhava* (I.10). The importance of light, food, and water for the growth and sustenance of plants was well known. The maximum age of a tree is given as ten thousand years, and the causes of death are cited as unsuitable food, accident, and disease. That plants move towards what is favourable and away from what is unfavourable was known. Post-Vedic Indians also noticed that some plants close up their leaves at night as if sleeping, that plants are sensitive to touch, and that various kinds of flowers open their petals at different times of the day.

Plants have been regarded as living beings since Vedic times. A concise but clear discussion on the existence of life in plants is given in the *Mahābhārata* (XII.184). Further evidence is to be found in Guṇaratna's commentary on the *Śukranīti*, Udayana's *Kiraṇāvalī*, Śaṅkara Miśra's *Upaskāra*, and the *Bhāgavata Purāṇa*.

All the methods of propagation now known were common knowledge. Mention is made of propagation by seeds (*bījaruha*), roots (*mūlaja*), cuttings (*skandhaja*), graftings or layerings (*skandhe ropaṇīya*), apices (*agrabīja*), and leaves (*parṇayoni*). All these methods are referred to in treatises like the *Bṛhat-saṁhitā*, *Arthaśāstra*, *Manu-saṁhitā*, *Abhidhāna-cintāmaṇi*, and *Sumaṅgala-vilāsinī*.

The idea of sexuality in plants seems to have been only vaguely known, though there is a discussion in the *Śārīrasthāna* (I.12-14) of the *Hārīta-saṁhitā* as to how seeds are produced in plants. Only in one instance are a male and

[7] *Vaktreṇotpalanālena yathordhvaṁ jalamādadet;*
Tathā pavanasaṁyuktaḥ pādaiḥ pibati pādapaḥ. (16)
Tena tajjalamādattaṁ jarayatyagnimārutau;
Āhārapariṇāmācca sneho vṛddhiśca jāyate. (18)

[8] *Sacred Books of the Hindus*, Vol. VI (Panini Office, Allahabad), p. 177; cf. *Bhāgavata Purāṇa*, III.10.19-20.

a female plant distinguished, and that is in the case of *ketakī* (*Pandanus odoratisasimus*). The male plant is called *sitaketakī viphalā* or *dhūlipuṣpikā*, and the female, *svarṇaketakī*.

Ecology: Caraka and Suśruta classified lands according to the nature of the soil, climate, and vegetation into three categories: *jāṅgala*, *anūpa*, and *sādhāraṇa*. *Jāṅgala* is described as a region of open spaces where a steady, dry wind blows. It is pervaded by expansive mirages, has few rivers and rivulets, abounds in wells, and consists mainly of dry and rough sands. The plants common to the region are *khadira* (*Acacia catechu*), *asana* (*Terminalia tomentosa*), and *badarī* (*Zizyphus jujuba*), among others. The *anūpa* region is a marshy tract bordered by seas. Swept by cold wind, it is impassable owing to its network of rivers (*nadīmātṛka*) and sheets of accumulated rain-water. Some of the plants of this region are *vañjula* (cane or reed), *hintāla* (a kind of palm), and *nārikela* (coconut). The *Amarakoṣa* mentions the following plants as growing in the water of this region: *saugandhika, kahlāra, hallaka, indīvara, kumuda, padminī*, and *kokanada* (various varieties of lotuses and water lilies); *vāriparṇī* (*Pistia stratiotes*); *mūṣika-parṇī* (*Salvinia cucullata*); *jalanīlī* (algae); and *śaivāla* (moss). The *sādhāraṇa* or intermediate region has some of the features common to the other two regions. A few of the plants found in this region are *mandāra* or *pārijātaka* (coral tree) and *santāna* (kalpa tree). The rainfall in these regions is given in the *Arthaśāstra* (II.24).

Taxonomy: In the naming of plants a scientific and rational procedure was followed. For example, plants were named in accordance with their special association, medicinal and other properties, morphological characteristics, environmental association, and other noticeable peculiarities. Sir William Jones observed that 'Linneus himself would have adopted them had he known the learned and ancient language of this country'. Some plants derived their names from historical events. For instance, *bodhidruma* ('tree of enlightenment') received its name on account of its being the tree under which Buddha sat when he attained *nirvāṇa*. Medicinal properties were utilized in naming plants like *dadrughna* ('curer of eczema') and *arśoghna* ('curer of piles'). Examples of naming plants on the basis of some domestic utility are *danta-dhāvana* ('cleaning of teeth', i.e. a kind of tree of which the twig is used as a toothbrush) and *lekhana* ('writing reed'). Morphological features were embodied in *tripatra* ('three-leafed'), *pañcāṅgula* ('five-fingured'), and *śatamūlī* ('hundred-rooted'). *Māgadhī* ('native of Magadha') and *cāmpeya* ('native of Campā') were based on local association. The names *maruvaka* ('desert crane', i.e. a desert plant of which the flower resembles the shape of a crane) and *jalaja* ('water plant') emphasized environmental association. Special features and other characteristics are reflected in the naming of plants such as *phenila* ('lather-forming', i.e. soapberry) and *śāradī* ('autumnal').

Sometimes plants were given two names, one for their identification by the common people and the other to convey their medicinal or other properties. The former was called *paricaya-jñāpikā saṁjñā* and the latter, *guṇa-prakāśikā saṁjñā.* Thus the plant *sesbania* is called *vakra-puṣpa* ('with papilionaceous flowers') and *vraṇāri* ('antidote to boil'). Similarly, *Ricinus communis* is called *citra-bīja* ('with painted seeds') and *vātāri* ('antidote to rheumatism').

Classification was based upon three distinct principles: botanical (*udbhida*), medicinal (*virecanādi*), and dietetic (*annapānādi*). Botanical classification can be traced to the *Ṛg-Veda* (X.97) and *Atharva-Veda* (VIII.7.4). Manu gives an elaborate classification, as do Caraka and Suśruta. Their classifications include such divisions as: plant bearing fruit without flowers (*vanaspati*); plant bearing both flowers and fruits (*vānaspatya* or *vṛkṣa*); annual plant (*oṣadhi*); creeping plant (*vīrudh*); herb with succulent stem (*gulma*); and grass, including bamboo (*tṛṇa*).

Plant families as such were not recognized. But allied plants or varieties, or even different species, were grouped together into what may be called a genus, based on floral characters. The specific characters were taken primarily from the colours of flowers. Thus the genus *kovidāra* includes the white-, yellow-, and red-flowered species. The first one is, again, divided into two varieties. Similarly, *balā* includes four species: *balā, atibalā, mahābalā,* and *nāgabalā.*

Caraka divides plants of medicinal value into two main groups: purgatives (*virecana*) and astringents (*anupāna*), the number of the former being 600 and that of the latter 500. The astringents, again, are divided into fifty groups under ten *vargas* or major heads. These include every item of therapeutics. Suśruta, however, classifies plants under thirty-seven sections or *gaṇas.* All plants known to be of medicinal value up to his time are placed under one group or another.

Caraka classifies plants of dietetic value under seven *vargas*: *śukadhānya* (cereal), *śamīdhānya* (pulse), *śāka* (pot-herb), *phala* (fruit), *harita* (generally, green or yellowish vegetables or fruits), *āhārayogin* (oil), and *ikṣu* (sugar-cane). Suśruta classifies plants of dietetic value into fifteen *vargas*: *śālidhānya, ṣaṣṭhika, vrīhidhānya, kudhānya* (all cereals of different classes), *vaidala* (pulse), *tila* (sesamum), *yava* (barley), *śimba* (bean and its varieties), *phala, śāka, puṣpa, udbhida* (mushroom), *kanda, taila,* and *ikṣu.* He mentions more than thirteen varieties of sugar-cane.

Heredity: The concept of heredity was known to ancient Indians. In the *Caraka-saṁhitā,* and earlier still in the Brāhmaṇas, an explanation for the phenomenon of hereditary transmission was sought. Caraka and Suśruta, following Dhanvantari, hold that all the organs are potentially present at

the same time in the fertilized ovum and unfold in a certain order.

Pathology: Ancient Indian botanists made contributions to the study of plant pathology. The *Atharva-Veda* (VI.50) refers to the destruction of corn by pestiferous insects. Sāyaṇa's commentary on this gives a long list of such pests. Mention of blight and mildew occurs in Vinaya texts. The *Śukranīti* speaks of grains which are likely to be attacked with poison, fire, or snow, or eaten by insects. The *Arthaśāstra*, *Agni Purāṇa*, and *Bṛhat-saṁhitā* have each a chapter on Vṛkṣāyurveda. In the last-named book, etiology, diagnosis, and treatment of plants are given. According to Bhaṭṭotpala, Kāśyapa gives a prescription for diagnosing plant diseases. Among the remedies suggested are the removal of affected parts and the taking of preventive measures against fresh infection through the wound. Barrenness of plants was also considered a disease, for which certain remedies were prescribed.

MEDIEVAL PERIOD

During the period A.D. 600 to 1563 some medical treatises were composed which testify to further advance in the knowledge of botany. In these works, plants are more systematically classified from the medicinal point of view. The most outstanding work of the period was the *Śārṅgadhara-paddhati* by Śārṅgadhara (*c.* A.D. 1300). A chapter of this work called the *Upavana-vinoda* treats of many aspects of plants. Some of the topics discussed are classification of plants, selection of seeds, sowing, planting, watering after planting, protective and curative measures, proper nourishment, proper fertilizer content, and methods of propagation.

Botanical Research: Botanical research also received attention during this period. The possibilities of developing new species, already mentioned in the *Bṛhat-saṁhitā*, were further explored in the *Śārṅgadhara-paddhati*. Like Luther Burbank of the modern world, ancient Indian botanists tried to transform scentless flowers into very fragrant ones. Cotton plants were specially treated to produce fibres as red as burning fire, as yellow as the feather of a *śuka* bird, and as blue as the sky. The *Bṛhat-saṁhitā* and *Śārṅgadhara-paddhati* also mention that the study of plant life with reference to its environment was intensively made.

European Contribution: The study of botany in India from the middle of the sixteenth century was carried out by the Europeans who came to this country. The first to come were the Portuguese. Garcia d'Orta's *Coloquios Dos Simples E Drogas Da India*, published in 1563, contains descriptions of a large number of plants used as drugs. Another work which deals with medicinal plants, the *Tractado de las Drogas* (1578), is by C. Acosta.

The first contribution of genuine scientific value, however, was made by Henry Van Rheede, the Dutch Governor of Malabar, in his book *Hortus*

Malabaricus published between 1686 and 1703. An amateur botanist, Van Rheede had acquired a large collection of Indian plants. Notable contributions were also made by other Dutch botanists such as George Everhard Rump (*Herbarium Amboinense*), John Borman (*Saurus Zelanicus*—plants of Ceylon and Peninsular India), Hermann (*Flora Zeylanica*), and Nicholus Burman (*Flora Indica*).

John Gerard Koenig, a Danish botanist, arrived in India in 1768. With Heyne, Klein, and Rottler he formed a society called 'The United Brothers' for promoting the study of botany in India. The membership grew and before the close of the eighteenth century many others like Flemming, Hunter, Anderson, Berry, John Roxburgh, Buchanan-Hamilton, and Sir William Jones had joined. They used to exchange specimens amongst themselves and send specimens to botanists of established reputation in Europe. In this way many Indian plants came to be described by Retz, Roth, Schrader, and others in Europe. One member of this society, Rottler, published in Berlin descriptions of some of the new species. With the establishment of the French settlement at Pondicherry, Sonnerat and other French botanists sent out from time to time large collections of plants to Paris. These were described chiefly by Lamarck and Poiret.

A significant event was the founding of the Asiatic Society of Bengal in 1784 by Sir William Jones, a member of 'The United Brothers'. For more than a century the *Journal of the Asiatic Society* was the only organ in India for the publication of botanical research. The establishment of the Royal Botanic Gardens at Calcutta in 1787 through the efforts of Lt.-Col. Robert Kyd gave a new fillip to the study of botany in India. In the course of time it became the first recognized centre of botanical activity in India. Kyd was succeeded by Roxburgh who has been described as 'the Indian Linnaeus'. Roxburgh's first contribution was *The Plants of the Coast of Coromandel* (1795). In his monumental work, the *Flora Indica*, a systematic account of Indian plants was given for the first time in India. In addition, he compiled the *Hortus Bengalensis*, a catalogue of plants cultivated in the Royal Botanic Gardens, as well as detailed drawings of 2,533 species of plants indigenous to India. Among other important contributions of this period which grew largely out of the many collecting expeditions undertaken by botanists are the *Prodromus Florae Nepalensis* (1825) by Don, based on the Nepalese collections of Buchanan-Hamilton; a catalogue of plant collections by Nathanial Wallich; and the *Icones Plantarum, Spicilegium Nilghirense*, and *Prodromus Flora Peninsulae Indicae* by Robert Wight, the last in collaboration with G. A. Walker Arnot.

The work done by Griffith in the collection, description, and morphological analysis of thousands of species is notable. In the *Linnaean Transactions*, his researches on the ovules of *Santalum, Loranthus, Viscum*, and *Cycas* were published.

He also collected and wrote much on mosses, liverworts, marsiliaceae, and lycopods. After his death, his manuscripts and other studies were published in six volumes. William Jack's *Malayan Miscellanies*, Thomas Thomson's collections of the flora of north-west Punjab, north-west Himalayas, and Tibet incorporated in Kew's *Flora Indica* and *Flora of British India*, Royle's *Illustration of the Botany of the Himalayan Mountains*, and Voigt's *Hortus Calcuttensis* are some of the notable botanical works of the period based on wide surveys conducted by the writers. It may be mentioned that Jameson introduced the China tea plant in India during the first half of the nineteenth century.

Survey of the flora of the Indian subcontinent and neighbouring areas continued unabated with the progress of the nineteenth century. Sir Joseph Hooker explored the Sikkim and Khasia Hills. His monumental work in seven volumes, *Flora of British India*, was published between 1872 and 1897. Hooker discovered the magnificent species of rhododendron and wrote a superbly illustrated monograph on them. Two other monographs by Clarke, an associate of Hooker, on Indian Composetae and Cyrtandrancae were excellent contributions to the botanical literature of the period. Thomas Anderson introduced the cultivation of the quinine-yielding species of cinchona. Sulpiz Kurz published in two volumes *The Forest Flora of Burma* in 1877. Aitchieson's *List of Punjab Plants* was published in 1867. The study of systematic botany by Lindsay Stewart, Col. Beddome, Brandis, and others is also noteworthy. Stewart published his *Punjab Plants* (1869), Brandis his *Forest Flora of the North West Provinces of India* (1874), and Beddome his *Flora Sylvatica of the Madras Presidency* (1869-73), *Ferns of Southern India* (1863), and *Ferns of British India* (1865-75). Talbot published *A List of Trees, Shrubs and Woody Climbers of the Bombay Presidency*. Gamble's contributions include his *Systematic Account of the Indian Bambusa* and *Manual of Indian Timbers*. Other excellent works of the period are Duthie's *Upper Gangetic Flora* (1871) and Prain's *Bengal Plants* and *Flora of 24-Parganas and Sunderbans* (1897).

In the field of economic botany, Royle, Falconer, and Jameson were responsible for the successful introduction of excellent apples and many European vegetables. Much work was done for the improvement of fibre-yielding and other plants of economic importance. But the most noteworthy enterprises of the century in which botanists took the leading part were the cultivation of tea and rubber, introduction of cinchona, and development of forest resources. In 1883 the Government of India founded the 'Department for Dealing with the Economic Products of the Indian Empire', and George Watt was appointed its first Reporter. His monumental work, *The Dictionary of Economic Products*, is still unsurpassed as regards information and detail, and the economic section of the Indian Museum bears eloquent testimony to his magnificent researches and ideas.

Brongniart, the great French palaeobotanist, was the first to describe Indian fossil plants in 1828. In 1832 Hugh Falconer contributed his *Exploration and Classifications of Tertiary Fossils of the Sewalik Range*. Another important study was Forbes Royle's *Illustrations of the Botany of the Himalayan Mountains* which appeared in 1839.

The Indian Forest Department was established first in the Bombay Presidency in 1807. Growing interest in Indian forests led to its expansion in other Presidencies as well during the middle of the nineteenth century. In 1842 and 1847 codes of forest laws were drawn up. Botany was included in the course of study of the Department and several members of the Department subsequently made valuable contributions in botanical research.

The foundation of the Medical College in Calcutta in 1835 marked the beginning of the study of botany by Indians in Bengal, if not in the whole of India. Jadugopal Mukherjee was the first Indian to write a book on botany, *Udbhid-vicāra* (1869). The Indian Association for the Cultivation of Science was founded in 1876 by Mahendra Lal Sircar. Among other subjects, botany was taught in the laboratories of this institution. The Botanical Survey of India was established about 1890.

Mention may be made here of a number of Indians who made valuable contributions to the study of botany during the nineteenth century. Among them are: N.N. Banerjee, U. C. Datta, K. L. Dey, I. Jaykrishna, J. Mukherjee, T. N. Mukherjee, and J. B. Singh.

9

ZOOLOGY IN ANCIENT AND MEDIEVAL INDIA

EVEN as a dweller in caves and forests in the early Stone Age, man acquired considerable knowledge of animals, birds, fish, insects, and other creatures. As he gradually adopted a pastoral and agricultural life in the late Stone Age or early Bronze Age, several common species of these animals and birds were domesticated by him for the purposes of agriculture, transport, and food. The maintenance of domesticated animals necessitated a more thorough knowledge of their habits and needs. Thus, through observation, the acquaintance with animal life gradually became more systematic, leading to attempts at classification and the formulation of some basic concepts regarding the animal kingdom.

PRE-VEDIC AGE

The earliest evidence of interest in animal life in pre-Vedic India (4000-1500 B.C.) is provided by the findings of excavations in Baluchistan, Sind, and the Punjab. Various articles such as seals, terracottas, clay figurines, amulets, and potteries bearing engraved or painted representations of animals have been unearthed in these excavations. The figure of the humped bull is most commonly pictured. Other animals met with include the rhinoceros, tiger, lion, water-buffalo, bison, ram, hare, and ibex. Some species of birds and fish, and even the scorpion, are also portrayed. These demonstrate the familiarity of pre-Vedic Indians with a variety of domesticated and wild creatures.

Animal remains have also been discovered at various levels of these excavations. Thirty-nine different species have been identified, of which twenty-six are vertebrates and thirteen invertebrates. Among the vertebrates are the bull, buffalo, elephant, camel, horse, ass, goat, pig, dog, sheep, fowl, bear, jackal, monkey, wolf, squirrel, gavial, deer, mongoose, crocodile, tortoise, and some freshwater and marine fish. Some of the invertebrates are the snail, coral, mollusc, sponge, freshwater bivalve, and gastropod.

VEDIC AGE

The *Ṛg-Veda*, *Atharva-Veda*, and *Taittirīya Saṁhitā* mention the names of many kinds of animals as well as a few varieties of birds, reptiles, worms, insects, and fish. In some of these texts, horses and deer of different colours have been described.[1] Mention is also made of twenty-one varieties of peahen and even thirty-four ribs in a horse.[2] Some observations on the particular characteristics and activities of a few animals are noted in the *Atharva-Veda*: for instance,

[1] *Ṛg-Veda,* VII.42.2, II.34.3; and *Taittirīya Saṁhitā,* VII.3.18.1; V.5.15.1,16.1.
[2] *Ṛg-Veda,* I.191.14, I.162.18.

the impotence of a bull due to castration (III. 9.2); the croaking of frogs during the rains, their four-footed structure with speckled arms, and the three varieties of she-frogs (IV.15.13-15); cows devouring up their own foetal membrane after delivery (VI.49.1); the agility of the mongoose in fighting snakes (VI.139.5); the scorpion stinging with claws and tail (VII.58.8); insects injecting poisons by biting (VII.58.3.6); and the existence of twenty nails in the paws of a tiger (IV.3.3). The people of the Vedic age, therefore, apparently had an acquaintance with most of the creatures of the country at the time.

Some early attempts at the classification of animals are recorded in the *Taittirīya Saṁhitā* and *Atharva-Veda*. The *Taittirīya Saṁhitā* (VI.5.2.2) classifies animals mainly into two divisions: (i) those supported by bones (vertebrates) and (ii) those supported by flesh (invertebrates). Another classification (II.6.2.2) is on the basis of teeth: (i) those having incisors on one side and (ii) those having them on both sides. A third classification[3] is based on the colour and number of limbs. Classification of snakes[4] and worms[5] in the *Atharva-Veda* is based mostly on colour, form, and anatomical structure. Snakes are stated to possess two pairs of teeth, a pair of jaws, and a pair of tongues (VI.56.3). Twenty-one varieties of adders have been distinguished in the same text (I.27.4). References to the anatomical structure of the ox and horse are found in the *Atharva-Veda* (IX.12.1-18) and the *Taittirīya Saṁhitā* (V.7) respectively. More than fifty anatomical parts of the ox and about eighty of the horse are enumerated.

A fairly broad classification of animals has been made in the *Chāndogya Upaniṣad* (VI.3.1), which divides all living creatures on the basis of their seed (*bīja*), in a general sense their mode of origin, into the following three main groups: (i) *jīvaja* (viviparous), (ii) *aṇḍaja* (oviparous), and (iii) *udbhijja* (of vegetable origin). It was believed that the *udbhijja* animals arose from vegetable organisms. All mammals belong to the first group and all birds, reptiles, insects, and worms to the second group. The third group comprises minute animal organisms.

As members of a pastoral society, Vedic Indians were particularly interested in animal life and in the taming, training, and breeding of livestock. Special attention was given to the cow, bull, goat, sheep, and horse. Cows were highly valued for giving milk, and oxen for farm work. Stallions were sometimes gelded, while mares were exclusively used in driving war-chariots. Dogs were used for guarding houses and for hunting purposes. Sheep and goats were kept for their wool and flesh. Leather prepared from slaughtered animals was used for various purposes such as slings, bow-strings, chariot-traces, reins, and whips.

[3] *Taittirīya Saṁhitā*, V.5.22.1; V.6.12.1, 13.1, 14.1, 18.1, and 19.1.
[4] III.27.1-6, V.13.5-8, VII.58.4; cf. also *Tai. S.*, IV.2.8.3, V.5.10.1-2.
[5] II.31.4; II.32.2, 4-6; V.23.4, 6, 8, 9, 11-13.

POST-VEDIC AGE

Post-Vedic Indians acquired a much more comprehensive and detailed knowledge of animals, particularly in connection with the study of medicine. The *Caraka-saṁhitā* (IV.3.16) classifies all animals into four main divisions: (i) *jarāyuja* —born from the uterus (viviparous); (ii) *aṇḍaja* —born of an ovum or egg (oviparous); (iii) *svedaja* or *uṣmaja* —born of moisture and heat, spontaneously or asexually generated; and (iv) *udbhijja* —born of vegetable organisms. An almost identical classification occurs in the *Suśruta-saṁhitā* (I.1.22). But according to the commentator Ḍallaṇa (*c.* tenth-eleventh century), the divisions are not exclusive. For example, although bats and some varieties of cranes and herons fly, they are really viviparous. Similarly, among snakes the *ahipatākas*, a species of non-venomous colubrine snakes, are viviparous.

Caraka has also classified creatures according to their characteristics as follows: (a) *kṛmi* —parasites found in living creatures; (b) *kīṭa* —wingless insects; (c) *pataṅga* —flying insects; (d) *ekaśapha* —solidungulate animals; (e) *dviśapha* —cloven-footed animals; (f) *mṛga* —herbivorous animals; (g) *kravyāda* —carnivorous animals; (h) *śvāpada*— dangerous beasts of prey; (i) *vyāla* —beasts of prey; (j) *gomāyu* —creatures with poisonous fangs or stingers; and (k) *sarpa* —snakes.[6]

Caraka and Suśruta also made classifications of animals according to their food habits and habitats. Caraka (I.27.35-52) mentions the following groups: (1) *Prasaha* —creatures which grab and tear off their food. This group comprises carnivorous as well as non-carnivorous land quadrupeds and birds. Twenty-nine species have been referred to such as the lion, bear, camel, dog, tiger, wolf, vulture, osprey, hawk, horse, mule, panther, ass, cow, fox, and cat. (2) *Bhūmiśaya* or *bileśaya* — burrowing animals. Thirteen varieties of this category comprising mammals and reptiles have been noted, some of which are the frog, lizard, hedgehog, python, small mongoose, and porcupine. (3) *Ānūpa* —creatures that dwell in marshy and wet lands. In this group are nine varieties of mammals like the elephant, yak, rhinoceros, buffalo, and pig. (4) *Vāriśaya* —aquatic animals including mammals, reptiles, crustacea, and fish. Mention has been made of ten species in this class, like the tortoise, crab, crocodile, whale, oyster, and dolphin. (5) *Jalacara* or *ambucārin* —creatures that live around or on the surface of water. The crane, swan, flamingo, and pelican are some of the twenty-nine varieties in this group. (6) *Jāṅgala* —herbivorous animals, mostly deer, living in dry and hilly jungle lands and forests. Seventeen varieties of these have been named. (7) *Viṣkira* —gallinaceous birds that scatter their food in the process of eating. Nineteen species of this category have been noted, like the peacock, pheasant, partridge, sparrow, and quail. (8) *Pratuda* —birds that

[6] I.13.11; I.19.9; I.22.27; IV.8.59; VI.17.115; VI.23. 7-8, 201.

pierce or tear their food (worms and fruits) with their beaks. Thirty different kinds of these birds are mentioned, for instance, the bulbul, pigeon, Indian koel, kingfisher, mynah, woodpecker, and green parakeet.

Suśruta (I.46.29), on the other hand, classifies animals on the basis of their food habits and habitats into two main divisions: *ānūpa* and *jāṅgala*. *Ānūpa* is, again, subdivided (I.46.49) into five groups: *kūlacara*, *plava*, *kośastha*, *pādin*, and *matsya*. The *kūlacaras* are herbivorous quadrupeds that frequent the banks of rivers and ponds, for instance, the elephant, rhinoceros, and buffalo. The *plavas* are amphibious birds like the goose, duck, and crane. The *kośasthas* comprise molluscs such as the conch, pearl-oyster, and snail. The *pādins* are aquatic animals with pedal appendages, for instance, the tortoise, turtle, crocodile, and crab. The *matsyas* comprise freshwater and sea fish. The *jāṅgala* group comprises eight categories: *jaṅghāla*, *viṣkira*, *pratuda*, *guhāśaya*, *prasaha*, *parṇamṛga*, *bileśaya*, and *grāmya*. The *jaṅghālas* are wild, herbivorous quadrupeds that are strong-legged and quick-footed, representing various species of deer and antelope. The *viṣkiras* are birds that scatter their food while eating. The *pratudas* are birds that pierce or tear their food with their beak. The *guhāśayas* are carnivorous quadrupeds living in natural caves or hollows, and comprise the lion, tiger, wolf, hyena, bear, panther, cat, jackal, and others. The *prasahas* are birds of prey like the vulture, kite, hawk, and owl. The *parṇamṛgas* are arboreal animals such as the ape and squirrel as well as some species of reptiles and *carnivora*. The *bileśayas* are animals that live in holes or burrows, like some species of rodents, insectivora, and reptiles. Finally, the *grāmyas* are domesticated quadrupeds like the horse, mule, ass, camel, goat, cow, and sheep.

The *Suśruta-saṁhitā* (V.4.2-17) classifies snakes into five different genera or families. Of these, four—*darvīkara*, *maṇḍalin*, *rajimat*, and *vaikarañja*—are venomous while one is non-venomous. Of the four venomous families, three are pure or unmixed and one is hybrid. The *darvīkaras*, comprising twenty-six varieties, are hooded, swift in their movements, diurnal in their habits, and bear on their hoods or bodies the marks of chariot wheels, ploughs, umbrellas, cross-bands, goads, and so on. They are most deadly when young. The *maṇḍalins* (*vipera*), comprising two varieties, are thick, without hoods, slow-moving, and nocturnal in their habits, and bear circles or rings on their bodies. They are most deadly when middle-aged. Ten varieties of *rajimats* are noted. They are without hoods, nocturnal in their habits, and often of variegated colours on their upper parts and sides, and bear series of dots or marks. They are most deadly when aged. The *vaikarañjas*, of which ten varieties are named, are hybrid snakes. Of these, three are produced by the union of certain venomous species and seven are secondary derivative types. The *nirviṣas* or non-venomous snakes are of twelve varieties. Though without venom, they can kill, however, by strangulation and the crushing of bones. According to the *Agni Purāṇa*

(CCXCIV.11-12), the total number of teeth of a snake is thirty-two, of which four (two on each side) are fangs.

Among other creatures mentioned in the *Suśruta-saṁhitā* are twelve varieties (I.13.5) of leech (*jalaukā*) of which six are poisonous and six non-poisonous, sixteen varieties (V.8.50-51) of spider (*lūtā*), and the glow-worm or *indragopa* (V.1.12).

In his *Mahābhāṣya* (II.4.1-4) Patañjali (*c.* 150 B.C.) speaks of *kṣudrajantus* (small animals) and defines them variously as (i) animals without bones, (ii) animals without any blood of their own, (iii) animals so minute in size as to number more than a thousand in a palmful, (iv) animals not easily crushed, or (v) all animals up to the ichneumon in the animal series.

A more comprehensive classification of creatures is found in the ancient Jaina work *Tattvārthādhigama-sūtra* of Umāsvāmin (*c.* A.D. 40). This classification is based on the number of senses—two, three, four, or five—possessed by the animals. Creatures with two senses, namely, touch (as evidenced by contractibility of tissues) and taste (as indicated by their selection and rejection of food) are subdivided into (a) *apādaka* (*vermes* without lateral appendages); (b) *nūpuraka* (ring-like creatures with pendants, i.e. *vermes* with unsegmented lateral appendages); (c) *gaṇḍūpada* (knotty-legged *arthropoda* including crustacea, myriapod, and others); (d) some forms of mollusc like *śaṅkha* (conchifera) and *śuktikā* (pearl-oyster); and (e) *jalaukā* (leech).

Insects with three senses—smell, touch, and taste—comprise (a) *pipīlikā* (ant); (b) *rohiṇikā* (red ant); (c) *upachikā*, *kunta*, and *tupuraka* (bug and flea); (d) *trapuṣabīja* and *kārpāsāsthikā* (cucumber- and cotton-weevil and louse); (e) *śatapadī* and *utpalaka* (spring-tail); (f) *tṛṇapatra* (plant-louse); and (g) *kāṣṭha-hāraka* (termite and white ant).

Creatures with four well-developed and active senses—sight, smell, taste, and touch—include (a) *bhramara*, *varaṭa*, and *sāraṅga* (bee, wasp, and hornet); (b) *makṣikā*, *puttikā*, *daṁśa*, and *maśaka* (fly, gnat, gad-fly, and mosquito); (c) *vṛścika* and *nandyāvarta* (scorpion and spider); (d) *kīṭa* (butterfly and moth); and (e) *pataṅga* (grasshopper, cockroach, and locust).

Animals with five well-developed and active senses, besides man, are (a) *matsya* (fish); (b) *uraga* (apodal reptiles including snake); (c) *bhujaṅga* (limbed reptiles and frog); (d) *pakṣin* (bird); and (e) *catuṣpada* (quadruped).

Animals of the first three categories are invertebrates and those of the last are vertebrates. The vertebrates are subdivided on the basis of their mode of reproduction into three classes: *aṇḍaja*, *jarāyuja*, and *potaja*. *Aṇḍaja* (oviparous) comprises such animals as the snake, lizard, chameleon, fish, crocodile, and bird. *Jarāyuja* (viviparous) animals are mammals born with a placenta; for instance, man, cow, buffalo, goat, sheep, horse, tiger, bear, dog, and cat. *Potaja* animals are a class of mammals with deciduate placenta which is thrown

off as an afterbirth. These include the porcupine, elephant, hedgehog, hare, squirrel, ichneumon, mouse, bat, and insectivora.

Praśastapāda (*c.* fifth century A.D.) in his *Padārthadharma-saṅgraha* classifies animals into two main divisions: (1) asexually generated animals (*ayonija*) and (2) sexually generated ones (*yonija*). The latter are subdivided into viviparous (*jarāyuja*) and oviparous (*aṇḍaja*). The *ayonija* classification of Praśastapāda corresponds to the *svedaja* group of Caraka.

The *Rāmāyaṇa* and the *Mahābhārata* mention a great variety of animals including birds, snakes and other reptiles, insects, and fish. More than one hundred and twenty such names are enumerated in the *Rāmāyaṇa*. As in the *Chāndogya Upaniṣad*, the *Mahābhārata* (I.2.396; II.37.23) classifies mobile, living creatures into three divisions: *jarāyuja* (viviparous), *aṇḍaja* (oviparous), and *svedaja* (born of moisture). It describes fourteen different types of animals, seven domesticated and seven wild (VI.5.10-17). These animals are divided on the basis of their anatomical features into (i) those having many legs and (ii) those having two legs (XII.229.13). Interesting observations on diseases and certain natural habits of some animals are also found in this epic (XII. 212.48, 274.52-53).

Caraka and Suśruta lay special stress on the use of fish as a valuable article of food. Suśruta classifies edible fish into freshwater and salt-water varieties. Five varieties of fish and other aquatic animals are referred to in the Aśokan Pillar Edict V (*c.* 246 B.C.). These are (i) *anaṭhikamacche*, (ii) *vedaveyake*, (iii) *gaṅgāpupuṭake*, (iv) *saṁkujamacche*, and (v) *kaphatasyake*. These five varieties of fish have been identified by Hora as (i) the shark, though the word *anaṭhikamacche* literally means cartilaginous or boneless fish like the prawn, shrimp, jelly-fish, and starfish; (ii) the eel or eel-like fish; (iii) the freshwater porpoise; (iv) the skate and ray-fish; and (v) the globe-fish.[7]

In the *Arthaśāstra* of Kauṭilya (*c.* 300 B.C.) there are several references to fish and fisheries as well as to the rearing of such animals as the cow, buffalo, goat, sheep, horse, and elephant. In the chapter on the superintendent of cows, Kauṭilya defines as one of the duties of the superintendent the classification of cattle as calves, steers (tameable ones), draught oxen, bulls for ploughing, breeding bulls, cattle fit for the supply of meat, buffaloes and draught buffaloes, female calves, young cows, heifers, pregnant cows, milch cows, barren cows, etc. In another chapter Kauṭilya discusses the breed, age, colour, marks, group or class, etc. of horses. Kauṭilya also speaks of elephants in a separate chapter and classifies them into four groups on the basis of the training they are given: *damya* (tameable), *sānnāhya* (trained for war), *aupavāhya* (trained for riding), and *vyāla* (rogue elephants). Each of these is again subdivided into several groups.

[7] S. L. Hora, *Journal of the Asiatic Society of Bengal*, XVI (1950), pp. 43-56.

Some ancient treatises of uncertain dates like the *Hastyāyurveda* (*Gajāyurveda*) by Pālakāpya, *Aśvāyurveda* by Gaṇa, and *Aśvacikitsā* and *Aśvaśāstra* by Nakula deal with the treatment of diseases of elephants and horses. The *Aśvaśāstra*, concerning the anatomy, life, characteristics, and training of horses, is based on the observations of Śālihotra, the author of an earlier work of the same name who is believed to be the founder of veterinary science in ancient India.

The Tamil Saṅgam literature of South India abounds in references to a great variety of mammals and birds, and a few species of insects, reptiles, and fish. The composition of the various works constituting this literature, according to some scholars, spreads over the period from the fourth to the eighth century A.D., while others ascribe to them a much earlier date commencing from several centuries before the Christian era. The descriptive accounts of animal life recorded in these works reveal attempts at a serious study in natural history by the people of India in those early days. The habits, modes of life, and ecological distribution of many animals and birds can be gathered from these accounts. Several varieties of parrots are recognized, some noted for imitative speech, some for carrying messages, and some others for use as ornamental pets. They are said to be specially fond of the fruit of the *nimba* tree. It is recorded that soaring kites and vultures have the power of sighting their prey from a great height and of swooping down on them, picking them up in their sharp beaks, and then of soaring back to the sky. There are references to the habit of monkeys in sharing their food with their mates and to that of the male elephant of the desert region in peeling the bark of a tree called *yam* to squeeze out its water for the female to drink.

From the foregoing account it is clear that the Indians of the post-Vedic age had considerable knowledge of animal life.

MEDIEVAL PERIOD

During the medieval period (A.D. 600-1700) the study of animal life made little progress, though a few works deserve consideration. The *Bhaviṣya Purāṇa* (*c.* seventh century A.D.), for instance, gives some fresh information about the life of snakes. It is stated that the mating season of *nāgas* (snakes) is the months of Jyaiṣṭha (May-June) and Āṣāḍha (June-July), and that the gestation period is the rainy months that follow. They lay about two hundred and forty eggs in the month of Kārttika (October-November). Most of the eggs are eaten up by the parents. Those that are left, hatch in about a month or two. Eggs which are of a golden hue produce male offspring, those of a somewhat paler colour and an elongated ovoid shape female ones, and those of a different hue (like that of the *śirīṣa* blossom) hermaphrodite ones. After a week of their birth the young snakes turn dark; after a fortnight or three weeks their teeth and fangs appear. The venom reaches its maximum potency after twenty-five days. The snakes shed their skin in six months. When snakes move on the

ground, the folds of their skin on the under-surface alternately expand and contract, resulting in the projection and withdrawal of fine, filament-like legs, about two hundred and forty in number, the same as those of the joints on the skin (scales or scutes). A venomous snake is said to live for a hundred and twenty years, but the life span of the non-venomous species is somewhat shorter, about seventy-five years.

In the *Garuḍa Purāṇa* (*c.* A.D. 900) diseases of animals, particularly of horses and elephants, and their treatment have been described (CXCVII). The *Śāli-hotra* by Bhoja (*c.* eleventh century A.D.) is another treatise of this period on diseases of horses and their treatment. The *Aśvavaidyaka* by Jayadattasūri (*c.* sixteenth century) is a comprehensive treatise on the same subject.

Ḍallaṇa in his *Nibandha-saṅgraha*, a commentary on the *Suśruta-saṁhitā*, gives some precise and detailed descriptions of deer and birds based on their colour, habits of life, and other features. The sources of his information, how-ever, are not mentioned. He also quotes from an ancient writer, Lādyāyaṇa, a system of classification of *kīṭas* (insects and reptiles). According to this classi-fication, *kīṭas* are to be distinguished from one another by their peculiarities as follows: (i) dottings or markings, (ii) wings, (iii) pedal appendages, (iv) face with antennae or nippers, (v) claws, (vi) sharp-pointed hair or filaments, (vii) stingers in the tail, (viii) hymenopterous character, (ix) humming or other noise, (x) size, (xi) structure of the body, (xii) sexual organ, and (xiii) poison and its action on human bodies.

The Muslim rulers of India showed great interest in animals and their habits and modes of life as well as in their ecological distribution in and around the country. Considerable information on animal life is recorded in the memoirs of Babur and Jahangir as well as in the *Āin-i-Akbarī* of Abū'l-Fazl, the court historian of Akbar. Abū'l-Fazl mentions silkworms and certain animals of which no earlier record is known. These include a species of tailless ape (orang-utan) found in Bengal, a species of deer with two tusks but without horns occurring in the Kumaon hills (probably musk deer), and civet cat which emits a fragrance of which the Mogul emperors were particularly fond.

Jahangir, who was a lover of animals, contributed notably to the study of zoology. He made minute observations of their habits, behaviour, ecology, geographical distribution, and anatomy. He maintained a large menagerie and aviary which enabled him to study in detail the various animals kept there. He often dissected animals to verify popular notions about their anatomy. Among his original contributions are his studies of the *sarus* crane and the gestation period of the elephant. He is said to have made some experiments on hybridization between the ibex and the Barbary goat.

10

CHEMISTRY IN ANCIENT AND MEDIEVAL INDIA

THE beginnings of the science of chemistry in India can be traced to ancient times. Chemical processes were first utilized in practical arts such as the manufacture of decorated earthenware and porcelain, burnt bricks, glass beads, alloys, and medicines. The craftsmanship in these industries was of a high order suggesting that the artisans had a good working knowledge of the chemical processes involved. But it is doubtful if the understanding of theoretical chemical principles had developed to a great extent. Nevertheless, philosophical speculations about the cosmogenesis and nature of matter by ancient Indian thinkers led to the formulation of the concepts of the atom and chemical combination, which were not, however, supported by experimental data.

The origin and development of chemistry in ancient and medieval India may be studied with reference to the following periods: (i) pre-Harappan, Harappan, and post-Harappan; (ii) Vedic; (iii) post-Vedic; and (iv) Medieval.[1]

PRE-HARAPPAN, HARAPPAN, AND POST-HARAPPAN PERIODS

Copper articles and specimens of burnt clay which have been unearthed in Baluchistan and the neighbouring areas of Sind[2] show that the people who settled there around the fourth and third millennia B.C. laid the foundation of chemistry in India. Excavations at Mohenjo-daro in Sind and at Harappa in the Punjab[3] have shown that the people of the Indus valley civilization (*c.* 2500-1800 B.C.) were skilled in employing a wide range of chemical processes. Bricks, water-pots, vessels, jars, earthenware, faience, terracotta, jewellery, metal implements, seals, painted polychrome and glazed pottery, and other items have been found. The glaze was made of a fusible silicate (sodium silicate made from fusing soda with sand) mixed with colouring matter like ferric oxide and some types of copper ore. Quartz with clay was used for the body material. According to Mackay, the glazed pottery found at Mohenjo-daro represents the earliest specimens yet discovered, thus suggesting the possibility that glazed pottery is of Indian origin.[4] But there is evidence that the people of the Indus valley civilization had communications with those of the Sumerian culture in Mesopotamia and the Nile valley civilization in Egypt. Seals found in the

[1] *History of Chemistry in Ancient and Medieval India* incorporating the *History of Hindu Chemistry* by Acharya Prafulla Chandra Ray, ed. P. Ray (Indian Chemical Society, Calcutta, 1956), pp. i-ii.

[2] *Ibid.*, pp. 1-7.

[3] *Ibid.*, pp. 9-33; cf. P. Neogi, 'Copper in Ancient India', *Bulletin of the Indian Association for the Cultivation of Science* (Calcutta, 1918).

[4] Ray, *op. cit.*, p. 17.

excavations had glazes made of a fused mixture of powdered cornelian and soda. Oxides of manganese, copper, and iron were used for making coloured faience. Brown glazed pottery articles, both slip-glazed and paint-glazed, were the common varieties. The Indus valley people used lime, gypsum, and sand as constituents of mortar. They employed gypsum cement as plaster for houses.

In metal-working, the Indus valley people applied the processes of casting and forging. Among the metals used, copper and bronze were utilized for making tools, weapons, domestic utensils, statuettes, bangles, finger-rings, ear-rings, amulets, wires, and rods. Bronze was made from the smelting of mixed ores of copper and tin. Crude copper, first smelted in clay-lined pits in which charcoal was used as fuel, was later refined in clay crucibles. Crude copper, copper-arsenic alloy, and copper-arsenic-lead alloy were used for making cast objects, and refined copper for vessels and sound casting. A copper-tin alloy or bronze was preferred for sharp-edged tools. Gold was used for jewellery, and silver for jewellery and ornamental vessels. A gold-silver alloy, electrum, was found at Mohenjo-daro. Silver was extracted from an argentiferous lead ore.

A large variety of minerals and ores was known to the Indus valley people. These include lapis lazuli, turquoise, rock crystal, limestone, soapstone, alabaster, haematite, amethyst, slate, agate, jasper, chalcedony, onyx, bitumen, steatite, sodalite, jade, lollingite, arsenical pyrites, and several others. Most of these were found in the forms of ornamental beads, pendents, and other kinds of jewellery. Some like steatite were often coated with a glaze. Lollingite and leucopyrites were utilized for the preparation of arsenious oxide and arsenic. Cerrusite and cinnabar found at Mohenjo-daro were probably used for cosmetics and medicinal purposes. White lead was possibly utilized for plasters, eye-salves, and hair-washes. Galena was employed for the preparation of eye-salves and paints. The art of dyeing cotton with the red colouring matter of the madder root was also known. Excavations in southern Baluchistan have unearthed specimens of iron implements belonging to the post-Harappan period (*c.* 1800-1500 B.C.), indicating the knowledge of the use of iron in India even before the advent of the Aryans.[5]

VEDIC PERIOD

In the *Ṛg-Veda* there is mention of gold, silver, copper, and bronze. Golp was used for ornaments like anklets and rings. Metal vessels, tools, and armour were made mainly of bronze. All this affords evidence of the knowledge of metal-working. We also find reference to the tanning of hides for making slings, head-strings, reins, and whips. The dyeing of garments

[5] *Ibid.*, pp. 31-33; N. G. Majumdar, 'Exploration in Sind', *Memoirs of the Archaeological Survey of India*, No. 48.

with certain natural vegetable colouring materials and the preparation of fermented drinks from *soma* juice, barley grain, and milk (curd) are also mentioned in the same text. The *Yajur-Veda* speaks of lead and tin among other metals. Gold, according to the *Atharva-Veda* (XIX.26), was regarded as an effective agent for the prolongation of life. Lead was looked upon as an antidote to the spell of sorcery. Thus it may be inferred that several chemical processes were utilized during the Vedic period (*c.* 1500-600 B.C.).

POST-VEDIC PERIOD

The post-Vedic period (*c.* 600 B.C.-A.D. 800) forms the most flourishing and fruitful age as far as it concerns the development of the science of chemistry in ancient India. Chemistry was then closely associated with medicine. Moreover, these two subjects were dominated by the abstract philosophical theories and systems of the Upaniṣads. The physical and chemical theories of cosmic evolution as well as the methodology of science, for instance, were influenced by them.

Theory of Five Elements:[6] The Sāṁkhya-Pātañjala system of philosophy dealing with the process of cosmic evolution gives an account of the origin of the five elements (*bhūtas*)—earth (*kṣiti*), water (*ap*), fire (*tejas*), air (*vāyu*), and space or ether (*ākāśa*). This concept of five elements as the basis of the material universe is, however, much older. It occurs in the Āraṇyakas and the Upaniṣads (*c.* eighth century B.C.), and thus antedates the Greek theory of four elements—earth, water, air, and fire—formulated by Empedocles (*c.* fifth century B.C.).

These five elements postulated in the Sāṁkhya-Pātañjala system represent five abstract principles, or rather a classification of substances on the basis of their properties and states of aggregation. For instance, earth, water, and air may be viewed as comprising all the elements or compounds of chemistry in the solid, liquid, and gaseous states respectively. According to Sāṁkhya, these elementary substances consist of ultimate units called *aṇus* (atoms) which are made up of infra-atomic particles known as *tanmātras*. It admits that the properties of each of the *pañcabhūtas* vary with the grouping of *tanmātras* in the atoms of each.

In the Sāṁkhya-Pātañjala view, *ākāśa* functions in two different aspects: non-atomic and atomic.[7] In the non-atomic form it might be said to correspond to the hypothetical ether—an all-pervasive, ubiquitous medium—of nineteenth-century physics. Atomic *ākāśa* (*kāryākāśa*) is a derivative of non-atomic *ākāśa* (*kāraṇākāśa*). The former is charged with vibration potential, and the latter

[6] Vyāsa, *Yoga-bhāṣya*, II.19; IV.14; also Vijñānabhikṣu, *Sāṁkhyapravacana-bhāṣya*, I.62 and *Yoga-vārttika*, III.40.

[7] Vijñānabhikṣu, *Yoga-vārttika*, III.40.

behaves as a universal medium identified with space (*avakāśa*). The *ākāśa* atom, however, serves as the starting-point for the building up of the atoms of the other four elements. A similar view about the two different aspects of *ākāśa* is found in the Vedānta philosophy where they are distinguished as *purāṇaṁ kham* and *vāyuraṁ kham*. The former represents the *kāraṇākāśa*, the motionless, ubiquitous, primordial matter-stuff or matter-rudiment (known as *bhūtādi* in Sāṁkhya). The latter represents the *kāryākāśa*, a materialization from non-atomic *ākāśa*.[8]

The twofold aspect of *ākāśa*, non-atomic and atomic, related to each other as cause and effect with the atomic *ākāśa* serving as the basis of all other material atoms, may be regarded as a very significant concept of ancient Indian philosophy—a concept which seems to have some resemblance to modern ideas of continuous generation of matter in space and of space being filled with radiation as the starting-point of material creation.

Atomic Theory of Kaṇāda: Kaṇāda, founder of the Vaiśeṣika system of philosophy, primarily concerned himself with the concepts of atoms and molecules and their characteristic properties. He postulated four kinds of elementary atoms: *kṣiti*, *ap*, *tejas*, and *vāyu*. Regarded as material, these four elements are of two types, eternal and non-eternal. In his view, *ākāśa*, which is non-material, is one and all-pervasive, has no atomic structure, and serves merely as an inert and ubiquitous substratum of sound without taking any part in material evolution. An identical view is echoed in the Nyāya system. The Nyāya-Vaiśeṣika system, too, elaborately discusses atoms and their properties.

According to Kaṇāda, atoms are eternal, ultimate, indivisible, and infinitesimal. They possess certain characteristic properties and potentials of sense stimuli. *Kṣiti* has fourteen qualities, namely, colour, taste, smell, touch, numerical unit, mass, weight, conjunction, disjunction, distance, proximity, gravity, fluidity, and faculty; among them its unique quality is smell. *Ap* has the qualities of *kṣiti* with the exception of smell, instead of which viscidity is added; its special quality is taste. Excepting smell, taste, and weight, all the other eleven qualities of *kṣiti* are in *tejas*, its distinguishing quality being colour. Touch is the special quality of *vāyu*, which has the qualities of *kṣiti* excepting smell, taste, and colour.[9]

Kaṇāda's conception of atoms bears many points in common with that of the Greek philosopher Democritus (*c.* 470-360 B.C.). But the atomisms of Kaṇāda and Democritus failed to make any tangible contribution to the growth of science in India and Greece, because they were, by and large, mere speculations, though based on rational, systematic, and logical thought re-

[8] B. Seal, *The Positive Sciences of the Ancient Hindus* (Motilal Banarsidass, Delhi, 1958), p. 121.
[9] *The Vaiśeṣika Aphorisms of Kaṇāda*, trans. A. E. Gough (Oriental Books, New Delhi, 1975), p. 138.

garding the nature of matter and the structure of the universe, as also on the observation of some natural processes by the unaided senses.

Combination of Atoms: According to the Nyāya system, atoms possess a spherical shape (*parimaṇḍalīya*). Vācaspati Miśra (*c.* A.D. 840) indicates the position of one atom in space with reference to another by a geometrical analysis of the conception of three-dimensional space. He holds that in the original physical arrangement of atoms each spherical atom is surrounded by six others. Variations of this arrangement in the collocation of atoms and molecules give rise to the variety of mono- and poly-*bhautika* compounds. A conception of the arrangement of atoms in space constitutes an essential part of Kaṇāda's theory that chemical combination occurs under the influence of heat corpuscles. In the Nyāya-Vaiśeṣika view, atoms, though eternal in themselves, are non-eternal as aggregates which may be organic or inorganic.

According to the Vaiśeṣika system, atoms possess an intrinsic vibratory or rotatory motion (*parispanda*). By its original tendency, an atom combines with another atom to form a binary molecule (*dvyaṇuka*). The binary molecules thus formed by the combination of the atoms of the same element in pairs will possess the homogeneous qualities corresponding to the original qualities of the atoms only if there is no chemical transformation under the action of heat corpuscles. Combining among themselves by threes, fours, fives, etc., these binary molecules produce larger aggregates resulting in a variety of elementary substances. Another view in the Vaiśeṣika system maintains that the combination of atoms, which takes place either directly or by the successive addition of one atom to each preceding aggregate, may be in pairs, triads, tetrads, etc. to form accordingly a binary (*dvyaṇuka*), ternary (*tryaṇuka*), quarternary (*caturaṇuka*), and so on. A variety of substances results from the same element due to the differences in the molecular composition and configuration, particularly in the grouping (*vyūha*) or collocation (*avayavasanniveśa*). The elementary substances thus formed by the primary molecular combination may undergo qualitative changes and be decomposed into the original homogeneous atoms under the impact of heat corpuscles, which transform the character of the atoms and make them reunite in different groups or arrangements with different characteristic properties.

Two or more substances belonging to the same *bhūta* or to different *bhūtas* may also combine to form mono-*bhautika* or hetero-*bhautika* (simple and quasi) compounds. Homogeneous atoms of different substances of the same *bhūta* may unite to form mono-*bhautika* compounds, while bi- or poly-*bhautika* (hetero) compounds may be produced by the combination of heterogeneous atoms of substances belonging to different *bhūtas*.

Buddhist View of Atoms: The Vaibhāṣika and Sautrāntika schools belonging to the Hīnayāna sect of Buddhism accept the atomic view of matter. They

consider gross matter as a conglomeration of atoms that are impenetrable, indivisible, intangible, and unanalysable. These atoms, either simple or compound, are dynamic forces and undergo a continuous phase-change. The four types of elements—*vāyu*, *tejas*, *ap*, and *kṣiti*—formed by aggregation from their corresponding atoms with characteristic properties are known as fundamental atoms, while the four sensible qualities—touch, colour, taste, and smell—are secondary atoms. These elements combining with each other give rise to aggregates that are inorganic and organic substances.

Atomic Theory of the Jains: Matter, called *pudgala* in Jaina philosophy, acts as the vehicle of energy in the form of motion. It can exist in two forms: atomic (*aṇu*) and aggregate (*skandha*), the latter being formed from the former. *Aṇu*, an infinitesimal, eternal, and subtle particle having no parts, is both cause and effect. A *skandha*, being an aggregate of atoms, is not considered to be absolute and beginningless. A variety of *skandhas* from a *dvyaṇuka skandha* or *dvipradeśa* (binary aggregate) to an *anantāṇuka* (infinite aggregate) is formed by either the decomposition of large *skandhas* or the successive addition of an *aṇu* to the previous *skandha*. A *skandha* may, therefore, be made up of (i) a definitely large number of *aṇus* that may be counted (*saṁkhyeya*), (ii) an indefinitely large number of *aṇus* (*asaṁkhyeya*), (iii) an infinitely large number of *aṇus* of the first order (*ananta*), (iv) an infinitely large number of *aṇus* of the second order (*anantānanta*), and so on.

Every atom possesses an infra-sensible or potential taste, smell, and colour, and two infra-sensible tactile qualities—roughness or smoothness, dryness or moistness, hardness or softness, heaviness or lightness, heat or cold. A *skandha*, however, possesses in addition the following physical characteristics: sound, atomic linking, dimension, shape and configuration, divisibility, opacity, and radiant heat and light.

A very significant feature of the Jaina atomism relates to the mechanism of chemical combination and atomic linking. For the occurrence of chemical combination a mere juxtaposition of two atoms is not sufficient. They will combine under the following conditions: (i) when the atoms are endowed with opposite qualities such as roughness (*rukṣatva*) and smoothness (*snigdhatva*), provided the opposite qualities are not very feeble; or (ii) when atoms of similar character differ widely in the strength or intensity of their qualities. The properties of the atoms undergo change as the result of their chemical combination.

A detailed presentation of the atomic theory and chemical combination found in Umāsvāmin's (*c.* A.D. 40) *Tattvārthādhigama-sūtra* (V.26) may remind one of Empedocles's idea of four elements. It is also interesting to note that the Jaina theory of chemical combination bears some crude resemblance to the 'dualistic hypothesis' of Berzelius propounded in the early part of the nineteenth century.

Chemical Action and Heat: Many ancient Indian philosophical works, particularly of the Nyāya-Vaiśeṣika system, have noted the close association of chemical change with heat. According to Vātsyāyana (*c.* fourth century A.D.), chemical change may occur either by the application of external heat or due to the effect of internal heat. It was believed that the heat generated by the combustion of fuel existed in the fuel before in a latent form. In his *Kiraṇāvali*, Udayana (*c.* tenth-eleventh century A.D.) considered solar heat to be the ultimate source of all heat required for chemical change occurring on the earth. He thought that this solar heat was responsible for the change of colour in the grass; for the ripening of mangoes bringing about changes in their colour, smell, and taste; for the rusting of metals (combustion due to solar heat—*sūryapāka*); and for the conversion of food into blood. All these are instances of chemical transformation by heat.

Many early philosophers conceived of heat and light rays as consisting of infinitely small particles radiating in straight lines in all directions with inconceivably high velocity and with a sort of conical dispersion. These, on striking atoms, may break up their groupings, transform their physico-chemical character, and bring about chemical changes.

Indian and Greek Atomisms: In both ancient India and Greece, philosophical and scientific concepts were developed independently on parallel lines with distinctive features of their own. The Indian conception of the nature of matter and the structure of the universe, like that of the contemporaneous Greeks, followed a double tradition, viz. materialistic and religious. These two traditions were, however, often blended together, particularly in the case of the Indians.

The conception of *ākāśa* as both non-atomic and atomic is a distinctive feature of the atomic theory of ancient Indians. In both the Vaiśeṣika and Greek views, atoms are indivisible. In the Sāṁkhya-Pātañjala system, however, atoms are not indivisible in the strict sense of the term since they are made up of *tanmātras* in different proportions for each type of element. The atomism of the Nyāya-Vaiśeṣika school differs in conception as well as configuration from the Greek atomism. The Greek idea that atoms are real, of various dimensions, and in eternal motion is not found in the Nyāya-Vaiśeṣika atomism. According to the Indian theory, atoms have qualitative differences, but in the Greek view they differ quantitatively. A sort of mechanical concept of the universe postulated in Greek atomism is not at all mentioned in the Indian system. Furthermore, the soul, which is regarded as a composition of atoms in Greek atomism, is non-material, having no atoms, in the Indian view. However, the atomism of Kaṇāda as well as of Democritus, which anticipated the formulation of Dalton's atomic theory by several centuries, receded to the background for reasons already stated.

Kauṭilya, Caraka, and Suśruta: Literary and technical compositions of the post-Vedic period contain considerable information regarding chemistry, metallurgy, and medicine. The treatises of Kauṭilya, Caraka, and Suśruta are extremely rich in this respect.

Kauṭilya's *Arthaśāstra* (*c.* fourth century B.C.), although mainly a work on polity, is also a source-book of many branches of science in ancient India. This work describes the ores of gold, silver, copper, lead, tin, mercury (probably imported), and iron; the processes of extraction of their metals; and the preparation of their alloys. It explains the procedure of gold and silver working, and a process of silver purification in which silver and lead are heated in a skull—a technique somewhat resembling the modern cupellation process. It also describes a variety of gems like diamond, coral, sapphire, ruby, emerald, opal, and pearl. The composition of a variety of liquors is also discussed.

A definite progress in the chemical knowledge of the ancient Indian is found in the two well-known medical treatises, the *Caraka-saṁhitā* and the *Suśruta-saṁhitā*, believed to have been originally composed in about the first century A.D. but revised in subsequent recensions. Minerals like sulphate of copper, sulphate of iron, realgar, orpiment, rust of iron, sulphur, and pyrites have been mentioned in the *Caraka-saṁhitā*. The text also describes the use of coral, lapis lazuli, ashes of conch-shell, calces of iron and copper (oxides), and sulphide of antimony (as an ingredient of collyrium). The roasting of metals like iron and copper with sulphur is described as the 'killing' of these metals, meaning the formation of their sulphides. The preparation of various kinds of fermented liquors and of almost anhydrous alcohol by distillation has also been described.

An elaborate description of the preparation and properties of alkali carbonates and caustic alkali as well as of the neutralization of the alkali by an acid is given in the *Suśruta-saṁhitā*. This description is so perfect in detail that it could almost be transferred bodily to a modern textbook of chemistry. Caustic alkali was made by boiling a weak variety of alkali carbonate with a solution of lime.

Suśruta recommended as drugs the oxides (calces) of tin, lead, copper, silver, iron, and gold, which were prepared by roasting the metals with minerals like alum earth and red ochre. The poisonous property of the compounds of arsenic such as white arsenic and orpiment was known to him. Suśruta described a crude method known as *ayaskṛti* (action affecting the metals) of preparing metallic oxides or oxy-salts by roasting the metals with common salt, saltpetre, and sulphate of magnesia. It seems that mercury was not well known in Suśruta's time inasmuch as he only vaguely refers to it once or twice.

In the writings of the medical schools of ancient India originating from Caraka and Suśruta, references are often found to chemical composition and decomposition by more or less crude processes of calcination, distillation, sublimation, steaming, fixation, etc. On the basis of Sāṁkhya philosophy Caraka developed theories of chemical combination and the formation of compounds, and distinguished between chemical compounds and mechanical mixtures. Suśruta followed Caraka in this matter.

Caraka and Suśruta classified organic substances into two groups: vegetable and animal. Caraka made reference to vegetable as well as animal oil. Viscous (oily) substances were grouped under four heads: butter, oil, fat, and marrow. Salts were divided into mineral and vegetable types. Suśruta arranged poisons into two classes: vegetable and animal; but several poisons expressly termed as mineral poisons were included under the first category.

The chemistry of digestion has been elaborately discussed in the *Caraka-saṁhitā*, but a more detailed discussion is found in a medical treatise of a much later date, the *Aṣṭāṅgahṛdaya-saṁhitā* by Vāgbhaṭa (seventh-eighth century). The latter describes many preparations of gold, silver, copper, iron, tin, and lead.

Glass and Pottery: The process of melting, refining, and colouring glass was known in India as early as the sixth century B.C. This is borne out by the discovery of the earliest specimen of true glass in India (*c.* fifth century B.C.) which was unearthed at Taxila in the Bhir mound. Further evidence is provided by the find of the site of an ancient glass factory, believed to be of about the fifth century B.C., at Kopia in the Terai region of Uttar Pradesh. Samples of glass beads, fragments of earthen crucibles with glass sticking to the inner side, and lumps of glass of different colours in various stages of formation were recovered from that site. Excavations at Piprahwa near Kopia also unearthed glass beads in a Buddhist *stūpa*.[10] According to Pliny, the art of making glass and of colouring it with the help of metallic salts or oxides was well known to the ancient Indian. This is evident from the results of analysis of certain porcelain-like fragments found at Taxila. Reference may be made to an observation by Pliny about the Indian glass as being superior to all others.[11] Green and blue glass bangles, generally opaque but occasionally transparent, belonging to the Śaka-Parthian and Kuṣāṇa periods (*c.* 300 B.C., A.D. 100), have also been recovered at Taxila.[12] Similar bangles of the Andhra culture (*c.* first century A.D.) have been found at Brahmagiri and Chandravalli in the Chitaldurg district of Mysore and at Sisupalgarh near Bhuvaneswar in Orissa.

[10]Ray, *op. cit.*, pp. 73-76; M. M. Nagar, *U. P. Information* (15 August 1949), p. 79.
[11]Pliny, *Natural History*, XXXVI, p. 66.
[12]Ray, *op. cit.*, p. 78.

Specimens belonging to the second century A.D. which were unearthed at Taxila reveal that the art of making painted, decorated, and glazed pottery was fairly well developed during the post-Vedic period. Excavations at Ahicchatra and Bhita in Uttar Pradesh and at Bangarh in Bengal have yielded specimens of similar pottery ware belonging to *c.* 300 B.C. - A.D. 1100. Most of these are wheel-made with a fair percentage of mould-made pots. Terracotta objects, beads, plaques, moulds, figurines, toys, large rings for the construction of wells, and other items belonging to the Śuṅga, Kuṣāṇa, and Gupta periods have also been recovered at Bangarh. In addition, lime and powdered bricks of the Gupta period which were used as mortar for making rammed concrete on the floor of buildings, as well as decorative bricks of the Pāla period, have been found there. Specimens of ancient pottery, mostly local, have been discovered during excavations at Arikamedu in Tamil Nadu. The local pottery recovered there is to a great extent wheel-turned, excepting large troughs, storage jars, and a type of portable oven. The imported pottery, mainly from Italy and many Mediterranean ports, found at Arikamedu belongs to the early Christian era. Both black-and-red and black-and-grey wares resulting from firing under oxidizing and reducing conditions respectively have been discovered. They are slip- and salt-glazed, giving rise to very picturesque effects. Beads of semi-precious stones, faience, and various coloured glass were manufactured on a large-scale at Arikamedu in those days.

Excavations at Brahmagiri and Chandravalli have uncovered specimens of painted slip- and salt-glazed, hand-made pottery of the Stone Age. These bear no resemblance to the Indus valley ceramics. Slow-wheeled pottery of the Iron Age (*c.* 200 B.C.-A.D. 50) and fast-wheeled varieties of the Andhra culture have also been unearthed in Brahmagiri. Wheel-turned, plain, and polished pottery belonging to *c.* A.D. 50 has been found by excavations at Sisupalgarh.

Copper Working and Casting: The craftsmanship and remarkable achievements in copper metallurgy of the ancient Indians are confirmed by both extant monuments and archaeological evidence. In the Rampurwa Aśoka pillar near the frontiers of Nepal, a solid bolt of pure metallic copper (*c.* third century B.C.) has been found, which measures 24½ inches in length with a circumference of 14 inches at the ends. A seven-foot high pure copper statue of Buddha weighing about one ton and belonging to the fifth century A.D. was found at Sultanganj in Bihar and later removed to the Birmingham Museum. This statue is provided with an outer garment sufficiently transparent to make the body visible. The figure seems to have been cast in two layers, the outer layer having been cast over the inner one presumably by the *cire perdue* process. The casting of the inner body was effected on an earthen mould in segments held together by iron bands. Lumps of copper ore and other small copper

figures found in the vicinity suggest that the smelting and casting operations were conducted at the site.[13]

The Chinese traveller Hiuen Tsang describes a colossal 80-foot copper statue of Buddha which stood near the famous Nālandā university in Bihar. It is believed to have been constructed during the reign of a king Pūrṇavarman. This figure of remarkable metallurgical skill must have disappeared very shortly afterwards as no further mention of it is found in later chronicles.

There is archaeological and other evidence that punch-marked and stamped or cast copper coins were issued by the Maurya, Śuṅga, Kuṣāṇa, and Gupta kings. Large copper plates have been in use in India from very early times, particularly during ceremonies associated with land grants. The Sohgaura plate (*c.* third century B.C.) discovered in Uttar Pradesh bears testimony to this. Silver and gold jewellery with granulation and filigree work which was made on copper and bronze moulds or dies has been found at Taxila (*c.* third century B.C.). Copper utensils were commonly used in religious ceremonies in ancient India.

Smelting of copper on an extensive scale about two thousand years ago is corroborated by geological evidence found in Chotanagpur in Bihar. Deposits of copper slags have been found in abundance on the hills all around the area. Many extinct copper mines are found in Rajasthan from which the metal was evidently obtained in ancient times. Copper mines were worked and copper smelting done in Madhya Pradesh, Uttar Pradesh, and Madras. Nepal was an important source of copper in ancient India.

Among copper alloys, bronze and brass were extensively used in ancient India for making utensils, water-vessels, coins, ornamental articles, images of deities, and other items. Brass was manufactured by heating copper with calamine and carbonaceous matter or by smelting mixed ores of copper and zinc. From the records of Hiuen Tsang, it seems that there was an unfinished brass temple of Buddha near Nālandā (*c.* seventh century A.D.).

Iron and Steel: Although the preparation and use of steel were known in ancient India, wrought iron was mostly produced. This is because the heat resulting from the charcoal fuel which was used in a crude form of blast furnace was insufficient to melt the iron resulting from the reduction of the ore and thus to absorb carbon to form pig iron.

Specimens of many iron implements and a large variety of weapons believed to have been produced in the fourth century B.C. were discovered by the excavation of numerous burial grounds in the gravelly mounds at Tinnevelly in Tamil Nadu. Iron slag and clamps belonging to the third century B.C. have been found at the Bodh Gaya temple. Archaeological excavations carried

[13] P. Neogi, *Copper in Ancient India* (The Indian Association for the Cultivation of Science, 1918) pp. 20-21.

out in the forties in many sites in the Doab, e.g. Ahicchatra, Hastinâpura, Rupar, Panipat, Atrañjikhora, and Alamgirpur, led to the discovery of painted grey ware with which iron was associated. Radio-carbon dating of these objects, which include arrow-heads, spear-heads, and axes of different shapes, places them between 1025 and 537 B.C. Iron implements found in many megalithic burials in South India at Tekwada, Brahmagiri, Piklihal, Maski, and other places also date from the eleventh and twelfth centuries B.C.

Excavations at Bangarh and Taxila have led to the discovery of a large number of objects made of iron belonging to the Śuṅga, Kuṣāṇa, and Gupta periods. The famous wrought iron pillar near Qutb Minar in Delhi, a noteworthy testimony to the skill and special technical abilities of the early Indian metallurgists, has withstood for centuries the onslaught of weather without any sign of corrosion. This twenty-four-foot high pillar with a diameter of 16·4 inches at the bottom and 12 inches at the top and a weight of more than six tonnes is supposed to have been constructed in the early fourth century A.D. The extensive use of iron clamps and beams in the temple at Bhuvaneswar (*c.* A.D. 640) provides another instance of large-scale production and working of wrought iron in early India.

Steel of a fairly high quality used to be prepared in ancient India by a technique very similar to the modern cementation process. It was deemed to be very precious. The reported presentation of a piece of steel weighing about 30 lb. to Alexander the Great by the Indian ruler Porus corroborates this.[14] The use of fine steel implements is suggested by the nicely and precisely carved stone inscriptions of Aśoka. Descriptions given in the *Suśruta-saṁhitā* indicate that steel surgical instruments were also used. The steel produced in Hyderabad, Mysore, and Salem was exported to western countries as early as the beginning of the Christian era and was used for the preparation of the famous Damascus blades. The art of tempering steel was also known to the ancient Indians[15] from whom the Persians and, through them, the Arabs learnt the operation.

Dyes, Paints, Cosmetics, and Cement: The use of dyes like indigo, lac, turmeric, madder, resin, and red ochre was known to the ancient Indians. Varāhamihira (*c.* A.D. 550) in his *Bṛhat-saṁhitā* refers to mordants like alum and sulphate of iron for the fixing of dyes on textile fabrics. Relics of the fourth to the second century B.C. excavated at Taxila and Andher as well as the inscriptions in Kharoṣṭhī (*c.* first century A.D.) from Khotan bear evidence of the use of carbon or black ink.[16] The Ajantā cave paintings (*c.* fifth century A.D.) testify to the use of colouring materials.

[14]See *Journal of the Royal Asiatic Society*, Vol. V (1839), p. 395.

[15]See Varāhamihira, *Bṛhat-saṁhitā*, XLIX.23-26.

[16]*Report of the Archaeological Survey of India*, 1929-30, p. 209; cf. P. K. Gode, *History of Ink Manufacture in Ancient India*, Vol. III (Prachyavani, 1946), pp. 1 and 10-11.

The *Bṛhat-saṁhitā* (LXXVI) alludes to cosmetics, scented hair dyes, frankincense, delicately blended perfumes, etc. It also contains information on various cement preparations which may be classified under two heads: rock cement (*vajra-lepa*) and metal cement (*vajra-saṁghaṭa*). These varieties of cement were applied primarily to the walls and roofs of temples and other buildings.

CHEMISTRY IN MEDIEVAL INDIA

Chemistry in medieval India was closely associated with alchemy which was an integral part of the Tāntric cult. Although the origin of alchemy in India may be traced to a date as far back as that of the *Atharva-Veda*, or even that of the *Ṛg-Veda*, practical alchemy reached its acme only during the Tāntric period. Alchemy, as is well known, has a twofold objective: (i) the preparation of an elixir of life and (ii) the production of the philosophers' stone for the transmutation of base metals into gold. Tāntric treatises, both Brāhmaṇic and Buddhistic, abound in recipes for such transmutation of base metals, particularly of mercury into gold. The *Rasa-ratnākara*, attributed to the famous Buddhist alchemist Nāgārjuna (*c.* eighth century A.D.), contains descriptions of alchemical processes and preparations of many mercurial compounds. It gives an account of many chemical processes like the extraction of zinc, mercury, and copper, and the preparation of crystalline red sulphide of mercury (*svarṇasindūra* or *makaradhvaja*). This medicament is still used as a panacea for many ailments by physicians in India following the indigenous system of medicine. The treatise also describes more than two dozen varieties of apparatuses (*yantras*) for carrying out various physico-chemical processes like distillation, sublimation, extraction, calcination, digestion, evaporation, filtration, fumigation, fusion, pulverization, heating by steam and by sand, and the preparation of many metallic compounds.

The *Rasārṇava* or *Devī-śāstra* (twelfth century), a Tantra of the Śaiva cult dealing with alchemy and chemistry, gives a description of the colours imparted to flames by various metallic compounds like those of copper, tin, lead, and iron. A variety of minerals and ores, the extraction of copper from pyrites and zinc from calamine, the distillation of alum (possibly giving rise to sulphuric acid), and the purification of mercury by distillation are described in this Tāntric text.

The alchemical ideas and treatises of India found their way to China and Tibet. The *Dhātuvāda* (*c.* eighth-ninth century), a Tāntric text in Sanskrit, found translated in the Tanjur division of Tibetan literature, gives an account of the deposition of copper on iron from a copper salt solution and the preparations of amalgams of copper and of white lead. The *Sarveśvara-rasāyana*, another Tāntric text in Sanskrit of the same time which is also translated in the Tanjur, explains the process of making cuprous sulphide. The preparation of

antimony by heating a mixture of stibnite and iron is mentioned in the *Rasendra-cūḍāmaṇi* (thirteenth century). This shows that the process was known in India much earlier than its discovery in Europe by Basil Valentine (1604). The preparations of calomel and of oil of vitriol (sulphuric acid) from alum, the use of alum as a mordant for dyes, and the extraction of zinc from calamine are described in the *Rasaprakāśa-sudhākara* (*c.* thirteenth century).

The ideas of the alchemists about the possibility of transmuting base metals into gold gradually lost their charm because of repeated failure of experiments. But the numerous preparations of mercury, iron, copper, and other metals obtained in the process came to be used in medicine. As a result, the compilation of a number of medical treatises dealing with the use of metallic preparations followed. One such work, the Buddhist treatise *Rasaratna-samuccaya*, contains a vast mass of the then existing chemical information but very little that is new and of intrinsic value. It treats of mercury, minerals, metals, gems, liquefaction, incineration, construction of apparatuses, purification of metals, and extraction of essences (active principles). A beautiful description of the location, construction, and equipment of a chemical laboratory is recorded in this treatise. A method of preparing mineral acids, particularly *aqua regia* (*śaṅkha-dravarasa*), by distillation has been given in the *Rasa-pradīpa* (*c.* 1535).

Unlike what happened in Europe, alchemy in India failed to develop into rational, scientific chemistry. As a result, it gradually became extinct.

Practical Arts: There is plenty of evidence of the application of chemical knowledge and processes in the medieval period, particularly relating to metallurgy and metal-working, gunpowder, saltpetre, mineral acids, alum, paper, ink, soap, and cosmetics. Heavy guns and cannons made of copper, bronze, and brass were used by the Mogul emperors. Instances of working with wrought iron on a large scale by means of forging and hammering are provided by the following: the iron pillar at Dhar (fourteenth century); the pillar on Mount Abu (fourteenth century); the large iron beams at Konarak and in the temples of Puri (*c.* twelfth century); and the big iron guns and cannons of the Mogul period as found at Bijapur, Hyderabad, and Murshidabad. Records of the preparation of steel swords at various places in India are found in the *Yuktikalpataru* (*c.* eleventh century) and *Śārṅgadhara-paddhati* (*c.* fourteenth century).

The tinning of copper vessels gained currency in India from the Middle Ages, possibly after the arrival of the Muslims. An alloy made of copper, lead, and tin, or of copper, lead, and zinc known as *bidery* (from Bider, a town in Andhra Pradesh), produced during this period, was used to make vases, basins, cups, etc. which were then inlaid with gold and silver. These products were made largely in Hyderabad, Bengal, and North-West India. Enamelling on gold and silver ornaments in different colours with metallic oxides mixed with

soda-lead glass was known all over India. From the beginning of the seventeenth century, or possibly even earlier, a method of recovering gold remaining as waste of gold working was in vogue. In this process the waste materials were boiled in an aqueous solution of a mixture of nitre, common salt, and alum. This solution evidently contained *aqua regia*. Gunpowder was introduced in India about the time of Babur (*c*. 1483-1530). Formulas for the manufacture of fireworks are found in the *Kautuka-cintāmaṇi* and the *Ākāśa-bhairava-kalpa* of the fifteenth century.[17] The preparation of mineral acids (dilute *aqua regia*) is described in several medical works composed in the sixteenth and seventeenth centuries.

Paper-making was introduced in India from China through Nepal in about A.D. 1000 and became a flourishing industry during the Mogul and Peshwa periods. The raw materials used were mainly worn-out clothes, old tents, barks of certain shrubs and trees, and similar substances. These were beaten into a pulp in a lime-lined water reservoir and then made into paper sheets with the help of moulds. Soap, made in India for the first time during the Mogul period, was prepared from trona or natron, common salt, sesamum oil, and goat's suet. The preparation of black ink in solid and liquid forms from lamp-black, gum, and the infusion of gallnut in water has been described in the *Rasa-ratnākara* of Nityanātha (thirteenth century). The preparation of cosmetics and perfumes was known from the sixth century A.D. A detailed description of several aromatic ingredients for the preparation of cosmetics and perfumes, and the technical processes and recipes for the preparation of different perfumed products are given in the *Gandhasāra* and the *Gandhavāda*, which were composed around A.D. 1000 on the basis of earlier texts dating from A.D. 500 to 1000.[18]

CONCLUSION

Chemistry in India was developed empirically and occupied itself, more or less, with the collection of accidentally discovered facts associated with various practical arts like ceramics, metallurgy, metal-working, and medicinal preparations without any recognition of the chemical principles or nature of the chemical changes involved in their pursuit. The result was that the thoughts and ideas could not germinate into scientific laws and theories based on experimental observations and verifications. Likewise, the mechanical skill displayed in the pursuit of practical arts could not develop into technology in the absence of guidance and suggestions from scientific knowledge. Chemistry was dominated more by seeing and believing than by thinking and knowing. After

[17] See P. K. Gode, 'The History of Fireworks in India', *Transactions of the Indian Institute of World Culture*, No. 17 (Bangalore, 1953), pp. 1-26.

[18] See P. K. Gode, 'History of Indian Cosmetics and Perfumery', *Studies in Indian Cultural History*, Vol. I, pp. 297-308; Vol. III, pp. 1-12.

the age of Nāgārjuna, Indian treatises provide very little new chemical information, though quite a large number of commentaries and compilations were composed till the end of the sixteenth century. Nevertheless, India's achievements in the use of minerals, metallurgical techniques, processing of chemicals of everyday use, extraction of metals from their ores, and craftsmanship in the manufacture of certain metal products, which required mastery of some chemical processes, were quite remarkable. Some of the technical skills exhibited by ancient Indian chemists and metallurgists were indeed noteworthy.

11

ĀYURVEDA

ĀYURVEDA, the traditional system of Indian medicine, is a special branch of knowledge on life dealing with both body and mind. This is implicit in the two components of the term *āyurveda*: *āyus* and *veda*. The former means *jīvita* or 'life',[1] and the latter, 'knowledge' or more precisely 'science'. The scope of the term *āyus* extends to the understanding of life in all its conditions and bearings. According to the *Caraka-saṁhitā* (I.1.41), *āyus* comprises *sukha* (happiness), *duḥkha* (sorrow), *hita* (good), and *ahita* (bad). *Sukhamāyuḥ* or a life of happiness is free from physical and mental disease; endowed with vigour, strength, energy, and vitality; and full of all sorts of enjoyment and success. *Asukhamāyuḥ* or a life of *duḥkha* is just the opposite. *Hitamāyuḥ*, a good life, indicates a life of honest disposition, self-control, and self-restraint, which is prone to do what is beneficial to this world and the next. The opposite of this is *ahita*. *Āyus* is also defined by Caraka as life with a body, sense-organs, three basic principles, and the soul; it is also a cycle of *nityaga* and *anubandha*, i.e. of perpetual change and progress (I.1.42). Āyurveda deals with these four conditions of life. It is also concerned with the prolongation of life.

SCOPE OF ĀYURVEDA

The scope of Āyurveda is not limited to physical health alone. It also seeks to promote a totality of physical, mental, and spiritual health in the context of man's interaction with his environment. Āyurveda is concerned with the origin of life and intelligence which are eternal. The wide scope of Āyurveda, in general, covers (i) cosmological and ontological speculations about the intrinsic relationship between matter and life; (ii) biological theories concerning (a) embryonic conception, (b) body, life, and soul, and (c) rules of genetics; (iii) physiological and pathological theories; (iv) food; (v) rules of health and longevity; (vi) diseases, their diagnosis and treatment; (vii) poisons and antidotes; and (viii) ethics.

ORIGIN AND ANTIQUITY

The origin and antiquity of Āyurveda have been examined from two considerations: (1) myth and tradition; and (2) historical analysis. Tradition has it that Āyurveda is of divine origin from Brahmā who later on communicated this knowledge to the Aśvins,[2] and from the twin divinities it came to

[1]The term *āyus* is derived from *i*, 'to go'. *Āyus* therefore means 'continuity of existence'.
[2]Aśvins—two celestial physicians represented as twin sons of the Sun.

Indra.[3] Its human tradition began with the transmission of this divine knowledge to two mythical personages, Bharadvāja and Dhanvantari, who in their turn were responsible for the two streams of Āyurveda, i.e. medicine and surgery. Traditionally, Bharadvāja specialized in both medicine and archery or *śalya*, that is, surgery.[4] It therefore appears that the two streams originated not from two persons but from one under two appellations. This is corroborated by the association of Dhanvantari with his incarnated name Divodāsa and subsequently with Bharadvāja in the *Ṛg-Veda* and later Vedic texts.[5] It is also believed that their two successors, Ātreya and Suśruta, were not two different persons, Suśruta, alias Bahuśruta, meaning 'an extremely learned person'.[6]

The divine origin of Āyurveda has been mentioned by Caraka and Suśruta as well as by later authorities.[7] Possibly some common sources were relied upon by these two medical authorities in this regard.[8] Caraka (I.30.27) holds this divine knowledge of Āyurveda as eternal, but considers it to have a beginning from its first systematized comprehension or instruction.

While tradition would have us believe in the eternity of Āyurveda, historical considerations lead us to trace its origin to pre-Aryan times. In fact, different streams of thought and ideas are found to have been incorporated through ages in the various branches of Āyurveda. Its medical corpus is an extension and systematization of earlier medical knowledge of the pre-Aryan and Indo-Aryan peoples. Its philosophical speculations and logical deliberations in the understanding of the creation of the world in the context of material components of the body and in finding out the aetiology of diseases are borrowed from different philosophical systems, particularly the Sāṁkhya and the Nyāya-Vaiśeṣika. These contributed to the development of Āyurveda as we have it today.

Pre-Aryan Medical Elements: Archaeological remains concerning pre-Aryan medical elements unearthed from different sites of Indus and pre-Indus cultures testify to rudimentary ideas about some medical and surgical practices. Surgical activities are inferred from trephined human skulls and curved knives from two pre-Indus sites, viz. Burzahom in Kashmir and Kalibangan in Rajasthan.[9] Medical practices inclusive of some health and hygienic measures

[3] *Aṣṭāṅgahṛdaya-saṁhitā*, I. 1.3; T.A. Wise, *Commentary on the History of Hindu Medicine* (Thacker, Spink & Co., Calcutta, 1845), pp. 2 and 5.

[4] *Mahābhārata*, XII. 203.19.

[5] *Ṛg-Veda*, I. 116.8; VI. 16.5; VI. 31.4; *Śāṅkhāyana Gṛhyasūtra*, II. 14; J. Filliozat, *The Classical Doctrine of Indian Medicine—Its Origins and Its Greek Parallels*, trans. Dev Raj Chanana (Munshiram Manoharlal, 1964), p. 6.

[6] Filliozat, *op. cit.*, pp. 6-8.

[7] Anima Sen, *Āyurvede Sāṁkhyaprabhāvaḥ* (Calcutta, 1963), pp. 5-6.

[8] Filliozat, *op. cit.*, p. 8.

[9] H. D. Sankalia, *Some Aspects of Pre-Historic Technology in India* (Indian National Science Academy, 1970), p. 64.

are indicated in excavations at Mohenjo-daro and Harappa. These comprise elaborate sanitary measures, arrangements for bath in specially-built chambers, and medicinal substances consisting of stag-horn, cuttle-fish bone, and bitumen.[10] The craniotomic operation described in the *Suśruta-saṁhitā* (IV.15.6-7), hygienic rules and regulations as part of medical practice, application of vapour bath in medical treatment,[11] and utilization of animal and mineral substances[12] in medical prescriptions are some of the instances of borrowing by the Āyurvedic system from earlier cultures.

Indo-Aryan Medical Elements: While pre-Aryan elements led to the development of some medical practices in Āyurveda, Indo-Aryan medical elements facilitated the growth of some concepts and theories. These are mainly noticed in (a) cosmo-physiological speculations about the three basic constituents of living organisms, viz. *vāyu, pitta,* and *kapha*; (b) ideas about the aetiology of diseases; and (c) belief in the association of medical treatment with god-physicians.

(a) Cosmo-physiological speculations relate to the humoral theory of Āyurveda which propounds that wind (*vāyu*), bile (*pitta*), and phlegm (*kapha*) are the three basic elements activating, sustaining, nourishing, and maintaining the life-principle. The origin of this theory may be traced to Indo-Aryan speculations regarding the three world-components, viz. air, fire, and water, which similarly sustain, maintain, and motivate the world. The cosmic element of *vāyu* or *vāta* (air) is considered the motor *par excellence* which activates the entire universe.[13] Its physiological manifestation is the vital breath or *prāṇa* which, according to Āyurveda, regulates all functions of life.[14] *Pitta*, which maintains the thermal balance of the body, is a manifestation in living organisms of the cosmic principle of *agni* (fire).[15] The cosmo-physiological aspect of *agni* is suggested by the Vedic epithet *vaiśvānara* and the Avesta expression *vahu-frayan*, both meaning 'the fire of digestion present in all animate bodies'.[16] The Āyurvedic notion of fire (*tejas*) in the body is nothing but an extended idea of the Indo-Aryan concept of *vaiśvānara*. The term *kapha*, meaning that which results from water, corresponds to the cosmic primordial water (*ap*). This primordial element was viewed by both the Indo-Aryans and Indo-Iranians as 'mother', as a 'vivifying liquid' (nectar). Some other epithets show it

[10] Filliozat, *op. cit.*, pp. 32-34.

[11] J. Jolly, *Indian Medicine*, trans. C. G. Kashikar (Munshiram Manoharlal, New Delhi, 1977), pp. 33-34.

[12] P. Kutumbia, *Ancient Indian Medicine* (Orient Longman, 1962), p. xxviii.

[13] Filliozat, *op. cit.*, pp. 61-62.

[14] *Suśruta-saṁhitā*, I. 14.4; *Caraka-saṁhitā*, I. 18.49; *Caraka-saṁhitā* (Shree Gulab Kunverba Ayurvedic Society, Jamnagar, 1949), pp. 538-39.

[15] *Caraka-saṁhitā*, I. 12.11, 21.9; *Suśruta-saṁhitā*, I. 21.10.

[16] Filliozat, *op. cit.*, pp. 56-59.

as the 'fluid matrix' from which the birth of living organisms was possible.[17] Its physiological element *kapha* in the human body is also credited with the same properties. Both *ap* and *kapha* signify the fluid-matrix in which all the operations of life are possible.[18]

(b) Āyurvedic theories and ideas about the aetiology of diseases are of two kinds, rational and irrational. The first kind is formulated on the basis of pathological conditions, while the second is rooted in the notion of superhuman and malefic agencies being the cause of diseases. Maladies classed under the second group are known as *ādhidaivika*. Āyurveda owes much to the Indo-Aryan or Vedic medicine for this idea of the irrational cause of diseases. Moreover, the elaborate theory of *doṣas*, i.e. abnormal conditions of the three basic elements as the main cause of disease, which developed in Āyurveda, is also suggested in a passage of the *Atharva-Veda* (I.12.3).

(c) The other Indo-Aryan element present in Āyurveda is the association of godheads with medical treatment. The important god-physicians of the Vedic medicine finding prominence in Āyurveda were Brahmā, Indra, Rudra (as Śiva), Sūrya or Agni, and the two Aśvins. Their active role as physicians in the Vedas is replaced by the Āyurvedic medical formulae which allude to different godheads for the cure of specific diseases.[19] This association of divinities with healing was a common aspect of ancient medicine throughout the world.[20] The authors of Āyurveda in order to glorify the medical prescriptions appear to have associated them with the renowned Indo-Aryan god-physicians.

ĀYURVEDA AND THE VEDAS

In its conceptual aspects Āyurveda has greater affinity to Ṛg-Vedic notions, while in practice it draws much from Atharva-Vedic medicine. Its relation to the *Atharva-Veda* is seen in its (i) twofold objective of the curing of disease and the attainment of a long life;[21] and (ii) anatomical and physiological ideas. Under the second category may be cited (a) three types of bodily channels—*hirā*, *dhamanī*, and *nāḍī*—used in the sense of duct in the *Atharva-Veda* and corresponding to *śirā*, *dhamanī*, and *nāḍī* of Āyurveda which mentions an additional channel (*srotas*);[22] (b) ideas of five vital breaths common in the two systems;[23] (c) osteological ideas in connection with the number and nomen-

[17] *Ibid.*, pp. 54-56.

[18] *Caraka-saṁhitā* (Jamnagar ed.), Vol. I, pp. 522-25.

[19] G. N. Mukhopadhyaya, *History of Indian Medicine*, Vol. I (Calcutta University, 1923), pp. 1-176.

[20] H. E. Sigerist, *A History of Medicine*, Vol. II (Oxford University Press, 1961), pp. 154-55.

[21] P. Ray, *History of Chemistry in Ancient and Medieval India* (Indian Chemical Society, Calcutta, 1956), p. 37.

[22] S. N. Dasgupta, *A History of Indian Philosophy*, Vol. II (Cambridge, 1952), pp. 290-91.

[23] *Atharva-Veda Saṁhitā*, X. 2.13; *Caraka-saṁhitā*, I. 12.8.

clature of bones;[24] and (d) *ojas* (albumen), the vital element in the body recognized in Atharvan medicine and in Āyurveda.[25]

The main points of difference between Āyurveda and the *Atharva-Veda* are in the concept and mode of treatment of diseases. The *Atharva-Veda* stresses the wrath of gods and influence of malefic agents as the causes of diseases more than imbalances in bodily elements which are given primary importance in the diagnosis of diseases in Āyurveda. Hence drug treatment predominates in Āyurveda whereas treatment by charms is emphasized in the *Atharva-Veda*.[26]

Āyurveda, which incorporates different traditions, has a distinct place alongside of the Vedas. It forms a *upāṅga*[27] of the *Atharva-Veda* and *upaveda* associated particularly with the *Ṛg-Veda*. It is sometimes called a *pañcama-veda* or fifth Veda. The epithet *upāṅga* is presumed to have come into use on account of the resemblance between Āyurveda and the medical portion of the *Atharva-Veda*. This relationship has been noted by Suśruta (I.1.5) himself and later on by others. Its appellation as a *upaveda* or minor Veda of the *Ṛg-Veda* occurs in the *Cāraṇavyūha*.[28] Āyurveda is mentioned as a fifth or distinct Veda in the *Brahmavaivarta Purāṇa* (I.16.9-10). Modern writers consider it as a Vedāṅga or an appendage of Vedic literature.[29] All the aforementioned epithets of Āyurveda point to its existence in some form during the composition of Vedic literature.[30]

Although glorified as an appendage of Vedic literature, Āyurveda as such is not mentioned there. A later Vedic text designates a medical treatise as *subheṣaja*.[31] The *Mahābhārata* first refers to Āyurveda with its eight branches of knowledge. It specifically mentions Āyurveda composed by Kṛṣṇātreya.[32] Buddhist texts name a number of diseases and their remedies,[33] but they do not refer to the idea of 'science of life'. Jaina texts categorize Āyurveda as *hīna-śāstra*.[34]

DEVELOPMENT AND DECLINE OF ĀYURVEDA

Āyurveda as systematized into eight parts appears to have developed

[24] Deviation is noticed in Suśruta's system of numbering bones, which are 300 in place of 360 maintained by others. A. F. R. Hoernle, *Studies in the Medicine of Ancient India*, Pt. I (Oxford, 1907), p. 113.

[25] *Atharva-Veda Saṁhitā*, II. 18; *Caraka-saṁhitā*, I. 30.7-12; *Suśruta-saṁhitā*, I. 15.18-27.

[26] V. W. Karambelkar, *The Atharva-Veda and the Āyurveda* (Nagpur, 1961), p. 11.

[27] The term *upāṅga* has been defined as *aṅgameva alpatvāt upāṅgam*, i.e. an accessary or small supplementary work having the same scope as the *Atharva-Veda*. Dasgupta, *op. cit.*, p. 279n.

[28] Karambelkar, *op. cit.*, p. 10.

[29] *Ibid.*, p. 11.

[30] Dasgupta, *op. cit.*, p. 276.

[31] *Ṛg-Veda Prātiśākhya*, XVI. 54.

[32] *Mahābhārata*, II. 11.25; XII. 203.19; Karambelkar, *op. cit.*, p. 31.

[33] Karambelkar, *op. cit.*, pp. 24-26.

[34] *Ibid.*, pp. 26-27.

abruptly, but this impression is due to paucity of written records concerning the early state of Āyurveda. These early treatises were superseded by the present recensions because of their growing popularity. A list of the early recensions is preserved, however, in the *Brahmavaivarta Purāṇa*.[35]

The history of Āyurveda may be divided into four stages: (a) the beginning period (*devakāla*), (b) the period of compilations (*ṛṣikāla* or *saṁhitākāla*), (c) the period of epitomes (*saṅgrahakāla*), and (d) the period of decline. These four periods are marked by three distinct types of Āyurvedic treatises.

Beginning Period: In this period Āyurvedic works were attributed to mythical, divine, and semi-divine, personages. These works are all lost. Important among them were the *Brahma-saṁhitā* composed of 100,000 *ślokas*, *Prajāpati-saṁhitā*, *Aśvi-saṁhitā*, and *Balabhit-saṁhitā*.

Period of Compilations: This period (*c.* 500 B.C.-A.D. 500) witnessed the compilation of the works of ancient teachers who were the founder-writers of different aspects of Āyurveda. These aspects or eight parts of Āyurveda include Kāyacikitsā (therapeutics), Śalya-tantra (major surgery), Śālākya-tantra (minor surgery), Bhūtavidyā (demonology), Kaumārabhṛtya-tantra (pediatrics), Agada-tantra (toxicology), Rasāyana-tantra (geriatrics), and Vājīkaraṇa-tantra (virilification).

(i) Kāyacikitsā relates to treatment of diseases affecting the whole body, which are supposed to originate mainly from disturbances of the three humours. The first and foremost compilation was the *Agniveśa-tantra* of Agniveśa, based on the teachings of Ātreya Punarvasu. This work dealt primarily with therapeutics but touched upon other aspects of Āyurveda excepting *śālākya*. The original compilation existed up to the time of Cakrapāṇidatta (*c.* eleventh century A.D.). The present available recension redacted by Caraka and Dṛḍhabala (ninth century A.D.) is the *Caraka-saṁhitā*, originally composed between the second century B.C. and second century A.D. Dṛḍhabala redacted the last seventeen chapters of the *Cikitsāsthāna* and the seventh and eighth books. This work was translated into several foreign and regional languages, the earliest among them being Persian (prior to the eighth century A.D.). Of the eight commentaries on this treatise written between the sixth and twentieth centuries A.D., the most important was the *Āyurveda-dīpikā* by Cakrapāṇidatta. A second work also based on the teachings of Ātreya is the *Bhela-saṁhitā*, quite possibly the earliest extant medical treatise.[36] Lost works belonging to the Ātreya school and quoted by different commentators on the *Caraka-saṁhitā* include the *Jatūkarṇa-tantra*, *Hārīta-saṁhitā*, *Parāśara-saṁhitā*, and *Kharanāda-saṁhitā*. All these existed up to the time of Śivadāsa (*c.* fifteenth century A.D.),

[35]Dasgupta, *op. cit.*, p. 432.

[36]See R. C. Majumdar, 'Medicine', *A Concise History of Science in India* (Indian National Science Academy, New Delhi, 1971), p. 222.

commentator on the *Caraka-saṁhitā*. Other works on therapeutics were the *Viśvāmitra-saṁhitā*, *Atri-saṁhitā*, *Kapila-tantra*, and *Gautama-tantra*.

(ii) Śalya-tantra (*śalya* literally means 'arrow') deals with the methods of removing foreign bodies; obstetrics; the treatment of injuries and diseases requiring surgery; and the use of surgical instruments, alkalis, bandages, etc. The *Suśruta-saṁhitā* is one of the great classics on Indian surgery, belonging to the Divodāsa-Dhanvantari school. The present recension is a redaction by Nāgārjuna. Various commentaries on this work were composed between the sixth and twelfth centuries A.D. Among them, Ḍallaṇācārya's *Nibandha-saṅgraha* found prominence. Lost works of other sages of the Dhanvantari school quoted in commentaries on *Suśruta* as late as the twelfth century A.D. included the *Aupadhenavata-*, *Puṣkalāvata-*, *Vaitaraṇa-*, *Gopurarakṣita-*, and *Bhoja-tantras*. Apart from these works, mention may be made of two other works on surgery: the *Karavīrya-tantra* and *Bhāluki-tantra*. The latter was mistaken as the *Bhela-saṁhitā*.

(iii) Śālākya-tantra is concerned with the treatment of diseases of the body above the clavicle and use of thin bars, small sticks or probes, etc. as instruments. The nine texts belonging to this group, viz., *Videha-*, *Nimi-*, *Kāṅkāyana-*, *Gārgya-*, *Gālava-*, *Sātyaki-*, *Śaunaka-*, *Karāla-*, and *Kṛṣṇātreya-tantras*, are all lost.

(iv) Bhūtavidyā treats of mental derangements and other disturbances said to be caused by demons and prescribes prayers, oblations, exorcism, drugs, and so forth as remedies. No separate works appear to have been composed on this branch of Āyurvedic medicine. But various chapters devoted to this subject found in larger works include the *Amānuṣapratiṣedha adhyāya* of the *Suśruta-saṁhitā*, *Unmādanidāna adhyāya* of the *Caraka-saṁhitā*, and *Bhūtavijñānīya* and *Bhūtapratiṣedha adhyāyas* of the *Aṣṭāṅgahṛdaya-saṁhitā* of Vāgbhaṭa II.

(v) Kaumārabhṛtya-tantra gives methods of treatment of child diseases caused by demons. Works in this branch, which are all extinct today, dealt with both child and female diseases. These included the *Jīvaka-*, *Pārāvataka-*, *Bandhaka-*, *Kaumārabhṛtya-*, and *Hiraṇyākṣa-tantras*.

(vi) Agada-tantra discusses methods of diagnosis and treatment of the bites of poisonous snakes, insects, etc. and of herbal or other poison cases. Works on this branch of Āyurveda mentioned in the commentaries on *Suśruta*, and *Caraka* include the *Kāśyapa-*, *Ālambāyana-*, *Uśana-*, *Sanaka-* or *Śaunaka-*, and *Lāṭyāyana-saṁhitās*. The originals of these are lost.

(vii) Rasāyana-tantra deals with methods of preservation and increase of vigour, restoration of youth, improvement of memory, and prevention of diseases. Five works on this subject referred to in commentaries and works on alchemy and iatro-chemistry are the *Sādhana-tantra*; three manuals ascribed to Vyāḍi, Vasiṣṭha, and Māṇḍavya; and the *Nāgārjuna-tantra*, all of which are lost.

(viii) Vājīkaraṇa-tantra concerns the means of increasing virile powers. The

known texts on this aspect of Āyurveda, now lost, were the *Kucumāra-tantra*, *Agastya-saṁhitā*, and *Kaupālika-tantra*. The last-named was primarily a work on surgery.

Period of Epitomes: The Saṅgrahas, appearing from about the seventh century onwards, were epitomes of earlier texts. These summaries were of two types: complete and partial. The eight complete texts extant today are the *Aṣṭāṅga-saṅgraha* of Vāgbhaṭa I, *Aṣṭāṅgahṛdaya* of Vāgbhaṭa II, *Gadanigraha* of Soḍhala, *Siddhayoga* of Vṛnda, *Śārṅgadhara-saṁhitā* of Śārṅgadhara, *Cikitsāsāra-saṅgraha* of Vaṅgasena, and *Yogaratṇākara* and *Bhāvaprakāśa* of Bhāvamiśra. Partial summaries include numerous works relating to aetiology, treatment of particular diseases, materia medica, science of pulse, diatetics, etc. Some of the extant works of prominence are the *Rugviniścaya* or *Mādhava-nidāna* of Mādhavakara, *Arkaprakāśa* of Rāvaṇa, *Cikitsāsāra-saṅgraha* of Cakrapāṇidatta, *Nāvanītaka* (Bower Manuscript), *Yogaśataka* of Śrīkaṇṭhadāsa, *Rājamārtaṇḍa* of Bhoja, and *Śataśloka* of Vopadeva.

Apart from the three aforementioned classes of Āyurvedic treatises, there exist two other separate types of work, viz. Rasagranthas or iatro-chemical texts and Nighaṇṭus or medical lexicons. Rasagranthas (from *c.* seventh century A.D.) are primarily concerned with rituals, alchemy, and chemistry. Their value as medical literature lies in the exposition of the medical philosophy of the Rasaśāstra school, particularly of its iatro-chemical ideas and practices, and the concept of inorganic remedies. Among the important works are the *Rasaratnākara* and *Ārogyamañjarī* of Nāgārjuna; *Rasahṛdaya* of Govinda; *Rasaratnākara* of Nityanātha; *Rasaratna-samuccaya* of Vāgbhaṭa; *Rasārṇava*; *Āyurveda-prakāśa* of Mādhava; *Rasendra-cintāmaṇi* of Rāmacandra; and *Rasendra-cūḍāmaṇi* of Somadeva. Nighaṇṭus (from *c.* tenth century A.D.) were developed for defining the medicinal substances mentioned in Āyurvedic texts. Some of them are the *Dhanvantari-nighaṇṭu*, *Madanavinoda-* or *Madanapāla-nighaṇṭu*, *Rāja-nighaṇṭu*, *Dravyaguṇa-saṅgraha*, *Rājavallabha-nighaṇṭu*, *Soḍhala-nighaṇṭu*, and *Ratnamālā*.

Period of Decline: The decline of Āyurveda began in the period of the Saṅgrahas when medical authorities started summarizing the classics and codifying them as separate treatises. This process accelerated in the post-Saṅgraha period with the total absence of new redactions, commentaries, etc. The disappearance of ancient Saṁhitās made the later Saṅgrahas faulty.[87] The decadence of Āyurveda is believed to have been caused by the following factors: (i) disappearance of the practice of dissecting dead bodies, which resulted from either Buddhist influence in the seventh and eighth centuries A.D. or disturbed political conditions or lack of encouragement and patronage

[87] *Caraka-saṁhitā* (Jamnagar ed.), Vol. I, p. 151; Gananath Sen, *Āyurveda Paricaya* (Visvabharati Granthalaya, Calcutta, 1944), pp. 25-26.

by Muslim rulers, producing an increasing number of poorly trained Āyurvedic physicians; (ii) lack of facilities for clinical studies due to want of hospitals during the medieval period; (iii) growing popularity of Unani medicine under the patronage of Muslim rulers; and (iv) popular apathy to the Āyurdevic system.[38]

BIRTH OF RATIONAL ĀYURVEDA

The birth of rational Āyurveda may be traced to the appearance of recensions of earlier medical texts by Caraka and Suśruta.[39] The date of redaction of the *Caraka-saṁhitā* may be assigned to the first century A.D. on the identification of Caraka with one having the same name who happened to be the court physician of Kaniṣka.[40] Suśruta's original text is believed to have been redacted by one Nāgārjuna[41] between the third and fourth centuries A.D. These two *Saṁhitās* bear testimony to the scientific research, patient investigation, and experimentation which preceded them and served as works of reference to students and research workers alike. This is also attested by Caraka (I.4.20).

Each of these two *Saṁhitās* deals with, among other subjects, anatomy, physiology, toxicology, psychic therapy, personal hygiene, and medical ethics. Some differences are noticed in their presentation and treatment. *Caraka*, an enormous compendium suffering from repetitions, contains a vast amount of floating tradition of considerable historical value whereas *Suśruta*, while sufficiently emphasizing earlier traditions and knowledge, is a much more compact and systematic work. In the treatment of subjects the two compendia follow two traditions—*Caraka* that of Ātreya, and *Suśruta* that of Dhanvantari. The former is divided into eight *sthānas* (books), namely, *Sūtra, Nidāna, Vimāna, Śarīra, Indriya, Cikitsā, Kalpa*, and *Siddhi*. The latter is arranged into five *sthānas*, viz. *Sūtra, Nidāna, Śarīra, Cikitsā*, and *Kalpa*, the sixth *sthāna, Uttaratantra*, being a supplementary work containing Śālākya-tantra, Kaumārabhṛtya, and Bhūtavidyā. Suśruta's division of six *sthānas* has been adopted by Vāgbhaṭa I and Vāgbhaṭa II in their respective works.[42]

Both Caraka and Suśruta discuss the eight branches of Āyurveda mentioned earlier, taking into account the following factors: (a) the organism (*śarīra*); (b) means of its maintenance (*vṛtti*), i.e. proper conduct, moral as well as

[38] *Caraka-saṁhitā* (Jamnagar ed.), Vol. I, pp. 181-82; *Pratyakṣa-śarīra*, ed. Gananath Sen, Pt. I (Calcutta, 1940), English Intro., p. 2 and Sanskrit Intro., pp. 14-25.

[39] Kutumbia, *op. cit.*, p. xxx.

[40] Filliozat, *op. cit.*, pp. 17-18, 22-25. The identification of Caraka with Patañjali (second century B.C.) is debatable.

[41] *Ibid.*, pp. 12-14. There were three or four Nāgārjunas, but which of them was the redactor of this medical compendium is still an open question.

[42] See Kutumbia, *op. cit.*, p. xix.

physical; (c) causes of diseases; (d) nature of pain and diseases; (e) action (*karma*), i.e. treatment; (f) effect (*kārya*) or the restoration of the patient to his normal state; (g) time (*kāla*), i.e. due regard to the influence of the seasons; (h) agent (*kartṛ*), i.e. the physician and his professional requirement; (i) means and instruments (*karaṇa*); and (j) prescription (*vidhiviniścaya*).[43]

PHILOSOPHICAL BASIS OF ĀYURVEDA

Physical and metaphysical speculations about matter and life form the philosophical basis of Āyurveda. It accepts that man, the subject of its treatment, is a part of the cosmic existence and represents the cosmos in miniature. In this respect, the Sāṁkhya-Vedānta view of cosmogony and the allied Vaiśeṣika view of inherent nature of substances have been incorporated in Āyurvedic treatises. All material bodies, according to Sāṁkhya and Vedānta, are evolved from the interaction of Prakṛti and Puruṣa, the dynamic (also material) and static (also conscious) principles of the universe respectively. Prakṛti is the substratum of three elementary components (*guṇas*) of creation: *sattva* (intelligence stuff), *rajas* (energy stuff), and *tamas* (matter stuff). The process of creation is said to be initiated in Prakṛti by the transcendental Puruṣa through a disturbance in the equilibrium of the three *guṇas*. The *guṇas* thus form the inherent components, though in varying degrees, of every living object.

Every living being may be represented as *karmapuruṣa* (individuated soul) in union with mind, sense-organs, and material body. This material body is composed of gross elements in the form of *kalā* (protective layer), *dhātu* (component matter), *mala* (eliminations), three *doṣas* (humours), *agni* (digestive fire), and *kriyā*. Each of the fundamental components and primary elements constitutes the living organism, imparting its specific nature and properties to the individual in the proportion in which it is present.[44] The materials (*dravya*) which form food and drugs, being compounds of the five *mahābhūtas*, are also mutations of Prakṛti.[45]

Life and matter, both having their source in Prakṛti and Puruṣa, are similarly constituted. The five gross elements (*mahābhūtas*), viz. *ākāśa* (space), *vāyu* (air), *tejas* (fire), *ap* (water), and *pṛthvī* (earth), together with their subtle aspects (*sūkṣmabhūtas*) form the common constituents of all objects, animate and inanimate. Caraka, following the Vedāntic view, declares each of the gross *bhūtas* to be a peculiar ultra-chemical compound of five original subtle *bhūtas*.[46] Each of the gross *bhūtas*, according to Suśruta, is mixed up with

[43] H. R. Zimmer, *Hindu Medicine* (Johns Hopkins University, Baltimore, 1948), pp. 90-91.
[44] *Suśruta-saṁhitā*, III. 1; *Uttaratantra*, LXIV. 2-3.
[45] *Suśruta-saṁhitā*, III. 1.12-14.
[46] *Caraka-saṁhitā* (Jamnagar ed.), pp. 521-22.

other *bhūtas*. Every substance is in reality penta-bhautic, and it is only the relative predominance of a particular *bhūta* or *bhūtas* in any substance that determines its class.[47]

Substances which possess sense-organs are animate, and those without them are inanimate. The role of the five elements in living and non-living entities is described in different Āyurvedic texts, particularly the *Suśruta-saṁhitā*. In living bodies *ākāśa*, constituted mainly of the *sattva* principle, is responsible for sound, the sense of hearing, porosity, bodily cavities, and functional subdivisions of the blood vessels and sinews into minute capillaries, etc. *Vāyu*, constituted mainly of the *rajas* principle, accounts for physical and physiological activities, and imparts the senses of touch and lightness. *Tejas*, constituted mainly of the *sattva* and *rajas* principles, is responsible for visibility of objects, the sense of sight, colour, continuity, digestion, anger, instantaneous response, and courage. *Ap*, composed mainly of the *sattva* and *tamas* principles, bestows the faculty of taste and accounts for fluidity, weight, coldness, unctuousness, and the formation of semen. *Pṛthvī*, formed mainly of the *tamas* principle, imparts solidity, weight, and the sense of smell.[48]

In a perfect body these five elements are in a state of equilibrium. But this state is almost impossible. Hence health is a state of optimum balance. The greater the approximation to this state, the better the health. Diseased and pathological conditions are but imbalances and deficiencies in these components.[49]

In non-living organisms *pṛthvī* contributes density, heaviness, and solidity; *ap* provides coldness, heaviness, softness, mobility, compactness, and unctuousness; *tejas* imparts roughness, dryness, and lightness; *vāyu* gives, in addition to what is contributed by *tejas*, subtlety and tactility; and *ākāśa* confers softness, diffusion, porosity, etc.[50]

Among living beings, man possesses something more in addition to the aforesaid general attributes of the five elements. It is the mind with its faculties like the emotions of pleasure and pain, volition, perception, will, reasoning, memory, reflection, and imagination. Due to different combinations of the *guṇas*, these mental faculties also differ from man to man and from time to time in the same man.[51]

Method of Induction: Ever since its very origin Āyurveda has concerned itself with the causes, symptoms, and remedies of diseases. Knowledge of these three aspects of diseases was considered essential in medical practice. Caraka, for instance, accepts the Nyāya theory of *pramāṇas* (sources of know-

[47] *Suśruta-saṁhitā*, I. 41.2, 8.
[48] *Ibid.*, I. 42.2; III. 1.20-21.
[49] Majumdar, 'Medicine', *op. cit.*, p. 237.
[50] *Suśruta-saṁhitā*, I. 41.3-7.
[51] Majumdar, 'Medicine', *op. cit.*, p. 237.

ledge) based on the law of causality associated with concomitant variations as well as the method of induction in determining the nature of a disease. *Pramāṇas* are of four types: *āptopadeśa* (testimony of trustworthy persons), *pratyakṣa* (perception), *anumāna* (inference), and *yukti* (reasoning).[52] The first, however, is not given as much importance as the other three. *Pratyakṣa* is based on contact with a thing by sense-organs. It is the basis of inference as the first concomitance of *hetu* (cause). *Anumāna* is based on cause and effect relationship obtained in three ways: from effect to cause, from cause to effect, and from attendant causes. *Yukti* correlates a set of causes or circumstances with an effect based on common sense.[53]

Āyurveda in its own way interprets the law of causation and the method of induction in the context of diseases. As regards the law of causation, two principal kinds of inference were adopted by Āyurvedic physicians in the diagnosis of diseases: (a) cause to effect, in which a disease was inferred from previous causes; and (b) effect to cause, by which a specific malady was attributed to certain conditions and habits of the patient. In addition, there was another type of inference in which a disease was diagnosed through early indications of its symptoms. A fourth type of inference was based on the study of variations in symptoms due to multiplicity of causes.[54]

In the method of induction three types of knowledge were employed, namely, the cause and effect relations (*nidāna*), invariable prognostication (*pūrvarūpa*), and concomitant variation (*upaśaya*).[55] The method was indispensable for diagnosis of diseases, ascertainment of their causes, and prescription of cures.

Logical Speculations in Medical Assemblies: The other aspect of logical and dialectical speculations concerned medical assemblies which used to be held for the advancement of knowledge and for overcoming opponents.[56] Both Caraka and Suśruta followed the Nyāya method in their arguments with opponents.

Three types of argumentation, excluding *tarka* of Nyāya, are met with in medical deliberations. These are *vāda* (academic discussion for arriving at right conclusions), *jalpa* (disputation in which a man in the wrong tries to defend himself by unfair means), and *vitaṇḍā* (disputation in which attempts are made to find fault with the opponent's view without offering any alternative thesis). These three methods were employed in Āyurvedic assemblies, friendly and hostile.[57] The *Caraka-saṁhitā* was an outcome of such friendly

[52] *Caraka-saṁhitā*, I. 11.7.
[53] Dasgupta, *op. cit.*, pp. 374-75.
[54] *Ibid.*, pp. 395-98.
[55] *Ibid.*, p. 397.
[56] *Ibid.*, pp. 377-84.
[57] *Ibid.*, pp. 377-78.

discussions between Ātreya and his pupils. This was also the case with the *Suśruta-saṁhitā* (III.3.18). According to Caraka, scientific and honest deliberations should have *pratijñā* (a thesis to be established) and *sthāpana* (establishment of the thesis).[58]

DISEASES: PRINCIPLE, DIAGNOSIS, AND TREATMENT

Disease, according to Āyurveda, is a condition of the body and mind which results mainly from abnormal states of the fundamental elements (*dhātus*) of the human system. Restoration of normalcy depends on proper understanding of the factors leading to physical and mental growth and decay.

Causes of Growth and Decay, Physical and Mental: Physical growth depends on the equilibrium of the three *dhātus* of the body comprising *vāyu*, *pitta*, and *kapha*. Decay of the body is caused by imbalances in the *dhātus*. These two conditions of equilibrium and imbalance are known as *dhātu-sāmya* and *dhātu-vaiṣamya* respectively. When the amount of these *dhātus* is in normal measure (*prākṛta-māna*), i.e. *dhātu-sāmya*, they are *prasāda-dhātus* and growth follows. When there is excess or deficiency in their normal measure (*dhātu-vaiṣamya*), they become *mala-dhātus* and cause decay. To help keep the *dhātus* in balance, Āyurveda prescribes food of different *rasas* (tastes), thus avoiding excess or deficiency of any particular kind of substance in the body.[59] Apart from substances inducing imbalances in the proportion of *dhātus*, several other factors are considered responsible for organic decay. These include: (a) excessive (*atiyoga*), inadequate (*ayoga*), and wrongful (*mithyāyoga*) contact with sense-objects; (b) climatic variations of heat and cold; (c) misuse of intelligence; and (d) three *doṣas* (deranged humours).[60]

The mind (*manas*), which is included in the category of sense-organs, is believed to be made up of the three *guṇas*—*sattva*, *rajas*, and *tamas*. Growth and decay at the mental level are said to be due respectively to the predominance of *rajas* and *tamas*. The factors responsible for organic decay as enumerated above also cause mental deterioration. The humour *vāyu* in a normal state bestows mental energy; in an abnormal state it causes decay in mental functions. The observance or non-observance of the regimens of life prescribed by Āyurveda also affects mental growth or decay.

Vāyu, Pitta, and Kapha: The concept of the three humours—*vāyu* (gaseous element), *pitta* (fiery element), and *kapha* (liquid element)—forms the basis of Āyurvedic medicine. According to Caraka, these are generated in the body

[58] *Ibid.*, p. 379.

[59] *Ibid.*, pp. 319-20; P. Ray, H. N. Gupta, and M. Ray, *Suśruta-Saṁhitā—A Scientific Synopsis* (Indian National Science Academy), pp. 32ff.

[60] Dasgupta, *op. cit.*, pp. 320-21.

as waste products in the process of assimilation of the various *rasas* or essences contained in food. Of all the waste products, *vāyu*, *pitta*, and *kapha* are regarded as being the most important, since they sustain the functions of the body when in proper measure or retard them when in a state of imbalance. In a balanced state they are termed *dhātu* (that which upholds) and in an unbalanced state they are called *prakṛti-doṣa* (constitutional *doṣa* or deranged humours).[61] In appropriate proportions, these *dhātus* contribute to the efficiency of all sense-organs and to the strength, colour, and health of the body, thus making for a man's longevity.

Vāyu, in its five forms, has the properties of dryness, coldness, lightness, immeasurable latent power, and great speed. It maintains a desirable equilibrium among the *doṣas* (humours), *dhātus* (physiological elements), and *agni* (heat) present in the body. Hence, Āyurveda declares that the body can function normally only when *vāyu* is in an undisturbed state. *Pitta*, in its five types, contributes to the process of *agnikarma* (metabolic combustion). Some of the functions of *agnikarma* are separation of digested food elements as chyle, excreta, urine, etc.; supplying colour matter to blood; and imparting motion to body activities, vision to the eye, and lustre to the skin. The principal activities of *kapha* or *śleṣman*, in its five forms, are strengthening and promoting bodily endurance and contributing to proper and healthy functioning of the body. Disturbance or balance in the normal proportion of the three elements, *vāyu*, *pitta*, and *kapha*, is stated to be caused by climatic conditions, the quantity of food consumed, abnormal or normal life-style, incongenial or congenial environment, and unfavourable or favourable natural phenomena.[62]

Doṣas are at the root of all diseases. The intensity of aggravation of a disease depends on the extent to which the three humours are deranged. Every *doṣa* does not, however, result in all its possible associated effects. In diagnosing a disease the physician studies the distinctive symptoms indicating derangement of one or more humours. There are five stages of *doṣa* in the development of a disease. Suśruta (I.21.18-39) enumerates them as (i) *caya*, the stage of aggression or accumulation of *doṣas* in general; (ii) *prakopa*, the stage when the accumulated *doṣas* are spread throughout the system; (iii) *prasāra*, fermentation of *doṣas*; (iv) *pūrvarūpa*, manifestation of premonitory symptoms; and (v) *rūpa*, full manifestation of the disease.

Digestion and Metabolism: Digestion and metabolism have an active role in the promotion or prevention of diseases. Proper and improper digestion depends on three factors: nature and quantity of food, body heat, and wind. Food produces body heat, and nourishes and maintains the organism through its metabolic transformations. Āyurveda divides food into two types, light and

[61] *Ibid.*, pp. 326, 334-35; *Caraka-saṁhitā*, I. 7.38.41.
[62] *Suśruta-saṁhitā*, I. 1.24-25.

heavy. Light food is easily digestible on account of the predominance in it of *tejas* (fire) and *vāyu* (air), the two principal factors helping digestion. Heavy food, owing to the predominance in it of *kṣiti* (earth) and *ap* (water, *rasa*, etc.), is incapable of promoting digestion.[63] Digestive fire (*pācakāgni*) is created and maintained by three vital *vāyus*: *prāṇa*, *apāna*, and *samāna*. Digestion takes place in the stomach after the food substance is propelled there by *prāṇa-vāyu* and is affected by heat, air, water, and fat in the system. On being thoroughly digested, food substances are turned into a form of food-chyle which is converted into an energy-giving bodily fluid known as *rasa*. This *rasa*—sweet, frothy, and mucus-like—becomes acid, issues out of the stomach, and excites the secretion of bile. According to Āyurveda, this *rasa* is pumped by the heart through twenty-four major channels and permeates the entire system. The nature and course of this *rasa* which runs through the whole system can be inferred from the growth, attenuation, or other modified condition of the body. *Rasa* also tranquillizes, lubricates, and vitalizes the system.[64] *Rasa* is first transformed into blood which is then converted successively into flesh, fat, bone-marrow, and finally semen. Each stage of transformation takes 3,015 *kalās* of time (80·4 hours). Hence *rasa* takes 18,090 *kalās* (about three weeks) to be converted into semen or menstrual fluid.[65]

Rasa obtains its colouring matter as it flows through the spleen and liver. In this coloured form, the potent *rasa* is known as *rakta* (blood). Suśruta declares blood to be endowed with the properties of smell, fluidity, red colour, and lightness. Different factors are responsible for the derangement of blood, e.g. those affecting *pitta* as also improper food, exposure to the sun or heat, excessive fatigue, and deranged condition of *vāyu*.[66] It may be noted that the metabolic process leads to the expulsion of *malas* (wastes or excretions).

Diagnosis of Diseases: Diagnosis of diseases involves proper knowledge about the patient's constitution, his strength and life expectancy, and the root causes of the malady. The patient's strength is ascertained from (a) his normal constitution in health; (b) the abnormality that has set in; (c) the predominance of the particular element or essence (*sāra*) in his constitution; (d) his compactness or lack of it; (e) his proportions such as stature; (f) things agreeable to his constitution; (g) his mental disposition; (h) his power of assimilation; (i) his age; and (j) the season of the year.

Having completed the preliminary examination, the physician proceeds to determine the state of humoral derangement of the patient. According to Caraka, the *doṣas* in any disease may coexist in different strengths and in as

[63] *Caraka-saṁhitā*, I. 5.3.
[64] *Ibid.*, VI. 15.5-10; *Suśruta-saṁhitā*, I. 14.4-7.
[65] *Suśruta-saṁhitā*, I. 14.12-13.
[66] *Ibid.*, I. 14.9; 21.23-30.

many as sixteen possible combinations. The principal *doṣa* in a combination is the one whose symptoms are all manifest and whose origin and alleviation conform to its diagnosis. That which is endowed with the characteristics of an opposite kind is called an accessory in the combination. The coexistence of two *doṣas* is called *saṁsarga* and of all the three, *sānnipātika*.[67] Āyurveda also accepts that a particular disease may be the cause of another disease. In such cases, several diseases are commingled and the primary ones are difficult to distinguish.[68]

Caraka recognizes three special aids to diagnosis: *āptopadeśa* (instructions of the wise), *pratyakṣa* (observation), and *anumāna* (inference). By *āptopadeśa* is meant verbal instructions on diseases regarding their strength, origin, symptoms, aggravations, development, etc. *Pratyakṣa* implies knowledge about a patient obtained through sense-organs, e.g. seeing his outward appearance, hearing changes in the voice and the sound of breathing as also the rumbling of the bowels, feeling the temperature and smoothness or roughness of the skin, tasting the urine, and smelling the exhalation. Under *anumāna* Caraka adopts the three traditional methods of induction mentioned earlier, viz. *nidāna*, *pūrvarūpa*, and *upaśaya*.

For diagnosis of a disease Suśruta takes into account the following: time and season of its first appearance; the caste of the patient; things or measures giving comfort to the patient; cause of the disease; aggravation of pain; strength of the patient; the nature of digestion and appetite; emission of stool, urine, and flatus or their stoppage; and maturity of the disease in regard to time.

The aforesaid diagnostic processes prevailed till the medieval period when the science of pulse (*nāḍīvijñāna*) came to be applied in the diagnosis of diseases. The objective of diagnosis by pulse is to determine the condition of the three *doṣas*. This science is believed to have been borrowed from Arabia or Persia.[69] Two supposedly ancient treatises bearing testimony to this science of pulse, however, are the *Nāḍīparīkṣā* of Rāvaṇa and *Nāḍīvijñāna* claiming to embody the teachings of Kaṇāda and Gautama. The *Śārṅgadhara-saṁhitā* (*c.* fourteenth century A.D.) and *Bhāvaprakāśa* (*c.* sixteenth century A.D.) mention this science but give no details of its application.

Treatment of Diseases: According to Caraka and Suśruta, success in Āyurvedic treatment depends on the physician, patient, medicines, and attendant. Factors governing the treatment are *puruṣa* (patient), *vyādhi* (disease), *oṣadhi* (medicine), *kriyā* (processes), and *kāla* (seasonal and climatic factors as well as the time and frequency of medication or surgical treatment).[70] In treating a

[67] *Caraka-saṁhitā*, III. 6.11-13.
[68] *Ibid.*, II. 8.10-40.
[69] Jolly, *op. cit.*, p. 22.
[70] *Suśruta-saṁhitā*, I. 1.27.

patient, his age, sex, physiological and mental strength, and constitution have to be taken into consideration. Surgical treatment is strictly prohibited for the weak, old, infirm, infants, and expectant mothers.

Diseases are classified as *āgantuja* (extraneous) and *śārīra* (constitutional); or, again, as *ādhyātmika* (generated inside the organism or the mind), *ādhibhautika* (due to adverse external causes), and *ādhidaivika* (due to fate, malign influences, or non-observance of rules of health).[71] According to the degree of intensity of a disease it is *sādhya* (curable by medical treatment or requiring surgical treatment), *asādhya* (non-curable), or *yāpya* (relievable by treatment).[72] Physicians are advised not to take up treatment of non-curable diseases. Signs of curable and non-curable types have been fully enumerated in Āyurvedic treatises. Suśruta includes general paralysis, leprosy, piles, fistula, urinary calculus, abdominal dropsy, and other diseases in the latter category.

Suśruta (I.35.13-14) speaks of three stages in the development of a disease: *anyalakṣaṇa* (a preliminary stage serving as an indicator of the approaching primary disease), *prāk-kevala* (the primary stage of the main disease), and *aupasargika* (secondary stage, appearing as a symptom derived from the main disease). He prescribes treatment in relation to six stages of *doṣa*: (i) accumulation or aggravation, (ii) derangement, (iii) spread in the system, (iv) premonitory symptoms of appearance of disease, (v) developed disease, and (vi) manifestation in the form of a sore. Commencement of treatment is advised at the first stage, failing that, at the second stage. Caraka examines the seriousness of a disease from three successive seats of affection, viz. external inclusive of the skin and the *dhātus* except *rasa*; vital parts, i.e. the arms, brain, and bone-joints; and internal (*koṣṭha*). Diseases are to be treated before they reach the second and third seats of affection.

Drugs (*auṣadha*) are material aids to the treatment of diseases. Āyurveda classifies drugs into two types: those giving strength and those curing diseases. Both of these are subdivided into three categories: plant substances, animal products, and minerals, which help replenishment of specific deficiencies or neutralization of several elements in excess in the patient's body or improvement of some bodily functions. Suśruta enumerates the specific physical properties of five elements in drugs and their physiological actions when taken. He classifies soil according to physical properties and suggests the soil suitable for growing medicinal plants.

The inherent properties of a substance, namely, *rasa* (taste), *guṇa* (quality), *vīrya* (potency), *vipāka* (assimilability), and *prabhāva* (inherent nature), may vary in different samples. But its real character remains unchanged even after drying, pulverizing, pasting, and other operations. *Rasa* pacifies deranged

[71] *Ibid.*, I. 24.4-9.
[72] Ray *et al.*, *op. cit.*, pp. 48-49.

humours; *guṇa* causes a particular effect when used either internally or externally; *vīrya* induces physiological actions; *vipāka* causes digestion of drugs; and *prabhāva* is a peculiar active force producing a characteristic physiological effect. The inherent properties help the curative action of any drug by augmenting, reducing, or balancing any loss, excess, or derangement of humours.

Rasas are six in number: sweet, acid, saline, pungent, bitter, and astringent. These tastes result from the presence of the elements of earth, fire, air, and ether in variable quantities along with water which serves as the origin of taste. Āyurveda specifies their respective physiological actions, on the basis of which they promote the cure of a particular disease.

Suśruta divides all drugs into two categories, viz. *saṁśodhana* (purificatory) and *saṁśamana* (pacifying). Apart from these two divisions, Caraka divides drugs into fifty *vargas* (groups) according to their supposed action on the different organs of the body or on particular symptoms of the disease. In addition to these *vargas*, Caraka describes two other classes of medicine: *rasāyana* and *vājīkaraṇa*.

Kriyās or processes involved in treatment aim at the correction and pacification of deranged humours. The two processes given by Caraka, viz. *santarpaṇa* and *aptarpaṇa*, coincide with the four processes of Suśruta, viz. *āhāra* (proper diet), *ācāra* (right conduct and medical regimen), *saṁśodhana* (eliminative or cleansing treatment), and *saṁśamana* (sedative treatment). The first two are included under *santarpaṇa*, and the last two along with *doṣāvasecana* (draining out of excited *doṣas*) come under *aptarpaṇa*.[73]

Āhāra consists of substances agreeing with the constituent elements of the patient, which retain their inherent properties even in combination with other substances. Suśruta dwells at length on the merits and demerits of different kinds of food and drink with reference to their effects on the human system. *Ācāra* implies observance of hygienic rules and a code of correct conduct as well as taking of prescribed medical diet. Hygienic rules comprises cleansing the teeth, washing the face, bathing, nail-paring, care of the hair, exercise, massage, etc. Correct conduct involves regulation of sex life, avoidance of sleep in day-time, correct posture for sitting, etc. Apart from these, Āyurveda lays down several rules for seasonal observances suitable for keeping the three *doṣas* in balance.

Saṁśamana treatment, divided into three sub-groups, *vāyu*, *pitta*, and *kapha*, consists in the administration of medicines which rectify the deranged *doṣas* and calm their excitement without promoting excretions, i.e. they 'suppress' the disordered *doṣas*. *Saṁśamana* is useful in the treatment of *dhātu-vaiṣamya* in its early stage. The process of *saṁśodhana* involves intake of medicines which remove collections of deranged *doṣas* through excretions, i.e. they 'clear up'

[73] *Suśruta-saṁhitā*. I. 1.20: *Caraka-saṁhitā*, III. 3.57-62.

the accumulated *doṣas*. This treatment involves five purificatory processes: *vamana* (use of emetics), *virecana* (use of purgatives), *śiro-virecana* (use of errhines to promote nasal secretions), *āsthāpana* (dry enemata) and *anuvāsana* (oily enemata) known collectively as *vastikarma*, and *rakta-mokṣaṇa* (blood-letting).

Apart from these five purificatory processes, Caraka describes six other supplementary modes which include *laṅghana* (lightening or attenuating aggravated *dhātus* and *doṣas* by fasting and physical exercise); *bṛṁhaṇa* (promoting nutrition by nutritive food, massaging, etc.); *rukṣaṇa* (imparting roughness and paleness of body in the case of rheumatism and such diseases); *snehana* (promoting secretions of oily matter and impurities by internal and external use of oleaginous substances); and *svedana* (causing perspiration). Mention is also made of spiritual guidance, propitiatory measures for obtaining divine grace, and exorcism to overcome evil influences.

In mental diseases, which result from derangement of the three *doṣas* along with disorders in the three *guṇas*, the treatment resorted to was the same as in the case of physical ailments, supplemented by performance of auspicious rites, sacrifices, expiatory ceremonies, etc.

Surgical Treatment: *Śalya* (surgery) in its denotative sense implies the removal of foreign bodies embedded in the system. In its connotative sense it includes treatment of diseases of a serious type, not amenable to medical treatment. Surgical treatment in Āyurveda is done in three stages, one following the other: (i) *pūrvakarma* (preparatory measures), consisting in fasting or light feeding of the patient, placing him in a suitable posture, and keeping ready surgical instruments and aids; (ii) *pradhānakarma* (principal measures), inclusive of surgical operations, expulsion of morbid matter, application of medicinal paste, bandaging, etc.; and (iii) *paścātkarma* (post-operative measures). Suśruta has given much importance to post-operative measures as they promote proper healing.[74]

There are eight principal surgical operations, viz. *chedana* (excision), *bhedana* (incision), *lakhana* (scraping), *eṣaṇa* (probing), *vedhana* (puncturing), *āharaṇa* (extraction), *visrāvaṇa* (draining. of fluids), and *sīvana* (suturing).[75] Twenty-four other processes are associated with operations. These include different methods of pulling out the extraneous matter; injecting into, or filling up, a cavity; cleaning or draining a body canal; sucking out the morbid matter; cleansing the cavity of a wound; etc.

Suśruta enumerates eighteen methods, apart from proper surgical operations, of removing foreign bodies embedded in the system. These involve use of instruments and appliances as well as techniques like water-flushing, blowing

[74]Ray *et al.*, *op. cit.*, pp. 82-84.
[75]*Ibid.*, p. 83; *Caraka-saṁhitā*, I. 10.15-18.

in air or spraying cold water, and squeezing.[76] Four different types of instruments and appliances are recommended for different purposes. These are *śastras* (cutting instruments), *yantras* (blunt instruments), *upayantras* (accessories), and *anuśastras* (minor instruments). Twenty different types of *śastras* are associated with eight types of surgical operations. The shapes, working ends, and types of the instruments were fashioned according to requirement. Suśruta formulates proper modes for holding and using the instruments. *Yantras* of 101 varieties distributed in six main types were used for operations on the outer surface of the body, probing the affected parts, and suction or injection of liquids from or into bodily orifices. The working ends of these instruments were mostly shaped in different types of animal faces. All types of instruments, both sharp and blunt, were made of hard metal or a suitable substitute and constructed according to the directions of experts. Tempering of iron instruments with alkaline solutions, oil, or plain water, honing of sharp instruments, and keeping them in receptacles after use are advised. There were twenty-five *upayantras*, some among them being a magnet, thread, bandage, and hammer. Among *anuśastras*, some were leeches, cautery and fire, glass, and rock-crystal. Suśruta recommends their use in special cases as substitutes for proper instruments and for delicate operations on young children and nervous patients.[77]

In surgical treatment special care is to be taken to avoid any injury to the vulnerable parts of the body. These are centres distributed all over the body where veins, arteries, ligaments, joints, and muscles unite to form a special type of plexus (*marma*). Suśruta (III.7.14-31) stresses that special skill and experience are required of a surgeon in diagnosing a *marma* injury. These *marmas* are the seats of *vāyu*, *kapha*, and *pitta* as well as of the three fundamental *guṇas*. Suśruta asserts that a thorough knowledge of *marmas* consitutes a major part of all surgical knowledge. Out of 700 minor veins, 98 are specially vulnerable. Physicians are strictly forbidden to open, sever, or pierce them on any account while surgical operations are being carried out. Some special types of surgical treatment recognized in Āyurveda are grafting (rhinoplasty), resetting of bones, removal of piles and fistulas, ophthalmic surgery, and dental surgery.

Two operational methods were in vogue which did not call for the use of surgical instruments: (a) cauterization by the application of heat or alkali, specially recommended for patients unable to undergo surgical operations; and (b) blood-letting by the application of leeches in *pitta* disorders, cupping with gourd-vessels in *kapha* disorders, and suction with implements made from hollowed animal horns in *vāyu* disorders. Blood-letting by venesection was also practised in serious types of blood-poisoning.

The post-surgical measures, according to Suśruta, are *sīvana* (suturing),

[76]Ray *et al.*, *op. cit.*, pp. 93-95.
[77]*Ibid.*, pp. 85-87.

bandhana (bandaging), and *ālepana* (plastering). *Sīvana* involves joining of open wounds by means of metal needles and threads of vegetable substances, animal skin and sinews, and horse mane. Fourteen different types of *bandhana*, making use of cotton, linen, chinese silk, and woollen fabrics, are recommended for different parts of the body. Two types of *ālepana*, absorbent and non-absorbent, are suggested for inflammation.

PRINCIPLES OF MEDICINAL PREPARATIONS

The preparation of medicines with special reference to their tastes, potency, inherent efficacy, and reactionary properties forms an important part of Āyurveda.[78] The science of pharmacy aims at retaining the medicinal properties of the ingredients of drugs with necessary modification. This modification, Caraka (VII.1.2) declares, is brought about by dilution, application of heat, clarification, emulsification, storing, maturing, flavouring, impregnation, and preservation, as also by the material of the receptacle. Drugs are derived from three sources: vegetable, animal, and mineral. Some of the important factors considered in preparing drugs are (a) correct estimation of the proportion of different ingredients; (b) preparation of medicines of high potency; and (c) digestibility and agreeability. When prepared, a medicine is named after its basic ingredient.

According to Caraka (VIII.3.6), a medicine is to be administered after taking into account the patient's age, physical condition, and digestive power as well as the state of the humours, blood, and medication. According to Suśruta (VI.64.30-33), a medicine may be taken on an empty stomach, just before meals, immediately after a meal, during a meal, in between two major meals, mixed or compounded with ordinary food, immediately before and again immediately after a meal, at repeated intervals of time irrespective of food, or divided into small portions with every morsel or mouthful of a meal or with alternate morsels. These timings are prescribed according to the nature and severity of the disease as well as the physical condition and constitution of the patient.

Āyurvedic medicines are generally compounded with bases like *ghṛta* (clarified butter), *taila* (oil), water, and milk. They are available as *kaṣāya* or *kvātha* (decoction),[79] *vaṭika* or *guṭika* (pills and balls), *modaka* (sweet uncooked pills), *puṭapāka* (roasted vegetable medicines given either as a pill or powder or as vegetable juice mixed with honey), *cūrṇa* (powder), *kalka* (paste of a plant), *svarasa* (natural vegetable juice), *leha* or *lehya* or *avalehya* (thick plant extracts with sugar to be taken by licking), *yavāgu* (gruel mixed with medicinal stuff),

[78] *Suśruta-saṁhitā*, I. 40.

[79] This decoction is prepared by mixing one part of medicine with four to sixteen parts of water and then boiling the mixture until one-fourth remains.

ariṣṭa or *āsava* or *surā* (fermented drink mixed with medicinal stuff), and *kāñjika* (fermented rice-gruel). Healing substances in these different forms were used in two types of medicine, tonic and curative.[80]

GENETICS AND EMBRYONIC DEVELOPMENT

Āyurveda pays due attention to human genetics. Bodily and mental characteristics of the future child are supposed to be predetermined, some derived from the father, others from the mother. The child owes all the stable components of its body like the hair, bones, nails, teeth, veins, arteries, and nerves to its father and the soft components like the muscles, blood, fat, bone-marrow, heart, umbilicus, liver, and spleen to its mother. Bodily strength, complexion, shape, robustness, delicacy of build, etc. are due to the nutrient fluids in the mother's body, while the faculty of sense-perception, wisdom and knowledge, the capacity for enjoying pleasure or suffering pain, and longevity are derived from the father. Health, constitution, brightness of complexion, intellect, and valour are said to be the result of physiological and spiritual harmony of the parents.[81]

Āyurvedic texts provide details about the various stages of development of the embryo. In the first month the foetus is a small mass of five elements. In the second month it becomes a solid ball, a lengthwise flesh excrescence, or a round mass, indicating the male, female, or neuter sex character respectively. The head, arms, bones, and consciousness grow in the third month. All the limbs, including the heart, take a definite shape in the fourth month. At this stage the foetus first acquires a consciousness of its surroundings through the action of its heart and begins to long for sense-objects. This longing is expressed vicariously through the mother, who is said to acquire a second heart. If at this stage of pregnancy or later the desires of the mother are repressed or made to remain ungratified, congenital defects are caused in the foetus and the future child may be paralytic, hump-backed, dwarf, lame, crooked-limbed, blind, or suffering from defects of the sense-organs. In the fifth month flesh and blood increase to a greater extent than in other months. The soul also becomes more animated in this month. In the sixth month hair on the head and body, nails, bones, sinews, arteries, etc. are formed, and the vigour and complexion of the foetus increase. Suśruta maintains that intellect develops at this stage. In the seventh month the limbs and organs of the body approximately attain their future shapes. In the eighth month the vital force in the heart of the foetus becomes restive and has a tendency to move to and fro between the two hearts of the mother and the child. Hence a child prematurely born at this stage stands the risk of immediate death due to possible lack of vital life-force.

[80] Jolly, *op. cit.*, pp. 30, 35-36.
[81] Ray *et al.*, *op. cit.*, pp. 11-12.

The delivery takes place in the ninth month or later, but an unusually prolonged period of gestation, carried late into the eleventh or twelfth month, is said to be a pathological condition requiring medical treatment or surgical interference. The foetus lies in a doubled-up position with its head downwards in the uterus. Hence under normal conditions at the time of childbirth the head should emerge first. Any departure from this is abnormal and a pathological condition.[82]

CODE OF CONDUCT FOR PHYSICIANS

Āyurvedic texts lay down certain rules for practitioners. The physician is expected to treat a patient as best as he can. One restriction is that only 'deserving' persons are to be treated. Both Caraka and Suśruta state that habitual sinners, persons who are morally degraded, or who indulge in killing as a profession are not to be considered as 'deserving' persons. The physician is reminded that his patients trust him for their lives. He should reciprocate this trust by taking the utmost care in treating them, looking upon them as his own children. But he should refuse to take up a case where he is convinced that the disease is incurable. He is advised to provide his patients with proper medical and nursing facilities. The physician is forbidden to attend to a woman patient in the absence of her husband or guardian. He is not to say or do anything which may impart a mental shock to the patient or his relations. All professional information is to be considered strictly confidential. The Āyurvedic physician is expected to have devotion to his profession and to learn by experience all through his life. He should develop an attitude of compassion towards his patients and, above all, a philosophical outlook in respect of the cases which prove fatal.

APPLICATION OF ĀYURVEDA TO OTHER FORMS OF LIFE

Āyurvedic theories and practices were also applied to animal and plant life. There are voluminous medical treatises on plant life (Vṛkṣāyurveda), horses (Aśvāyurveda), elephants (Hastyāyurveda), and the bovine species (Gavāyurveda). Besides these, general books on medicine also contain some portions dealing with veterinary science. Medical lexicons like the *Rājamārtaṇḍa* of Bhojarāja (*c.* eleventh century A.D.) contain extracts from the above treatises and also touch upon other animals. The *Yogasudhānidhi* of Vandimiśra contains a chapter on conception, obstetrics, and special diseases of female animals.

The principal work on Aśvāyurveda is the *Śālihotra-saṁhitā* of uncertain date. Extracts of it are found in the *Agni Purāṇa*. The *Śālihotra-samuccaya* of Kalhaṇa (*c.* twelfth century A.D.) is believed to be a redaction of the *Śālihotra-saṁhitā*. It is a voluminous work in sixty-eight chapters throwing light on different

[82] *Ibid.*, p. 20; Jolly, *op. cit.*, pp. 66-68.

aspects of the horse inclusive of anatomy, physiology, and pathological conditions requiring medical and surgical treatment and including information relating to breed, sex, age, and so on. The medical and surgical methods follow the classical precepts of Āyurveda. Other works were the *Aśvavaidyaka* by Jayadattasūri and *Aśvaśāstra* by Nakula. The latter was known for its illustrations of horses and knowledge of equine anatomy. Another work, the *Cikitsā-saṅgraha*, contains a glossary of terms and materia medica.

The extant exhaustive treatise on Hastyāyurveda, the *Pālakāpya-saṁhitā* attributed to sage Pālakāpya, is a voluminous work written in the form of questions and answers between the sage and his disciple Romapāda. This work deals with anatomy, physiology, pathology, major and minor diseases with medical and surgical treatments, and drugs and diet. The other work on this branch of knowledge is the *Mātaṅgalīlā* by Nīlakaṇṭhācārya.

A treatise on Gavāyurveda attributed to Gotama was presumably extant until the Middle Ages as quotations from it occur in the *Rājamārtaṇḍa*. Apart from diseases and their treatment, the text contained information on diet, breeding, calving, lactation, and milk.

The importance of Vṛkṣāyurveda may be assessed from discussions on this subject in works like the *Arthaśāstra*, *Bṛhat-saṁhitā*, *Agni Purāṇa*, and *Viṣṇudharmottara Purāṇa*. The information contained in these texts mostly relates to sowing and germination of seeds, manuring, growth, classification of plants, and their treatment in diseased conditions. The two available works on this branch of knowledge are the *Vṛkṣāyurveda* of Surapāla (*c.* tenth century A.D.) and the *Śārṅgadhara-saṁhitā* (*c.* fourteenth century A.D.), a medical compendium containing a chapter called *Upavana-vinoda* which deals with different aspects of plant life and concentrates on the aetiology, diagnosis, and treatment of plant diseases. Surapāla's work adopts the theory of *tridoṣa* in the diagnosis and treatment of internal diseases of plants.

LATER DEVELOPMENT OF ĀYURVEDA

A new type of Āyurvedic treatment, *rasacikitsā*, which incorporated iatrochemistry or metallic compounds, came into vogue from *c.* A.D. 1300. It sought to utilize bodily fluids (*rasa*) for repelling diseases and preventing senility, and thereby acquiring a long life. Numerous preparations of mercury, iron, copper, and other metals as formulated in alchemy were found to be helpful accessories in medicine. At first they were used cautiously and tentatively in combination with the recipes of Caraka and Suśruta mainly based on medicinal plants. Later, these preparations supplanted the old Āyurvedic herbal treatment. Mercury became a principal healing substance, of which numerous preparations are described in different iatro-chemical texts and even in general works on Āyurveda of the medieval period. Opium and several other foreign drugs were

incorporated into Āyurvedic pharmacology in about A.D. 1500. Mineral acids, tinctures, and essences also came to be used about the same time.[83]

SPREAD OF ĀYURVEDA OUTSIDE INDIA

The concepts and theories of Āyurveda have their parallels in the contemporary medical systems of Iran, Hellenic countries, and Mesopotamia. The influence of Āyurveda on Greek medicine is noticed particularly in respect of the theory of pneuma physiology. Both recognize the importance of wind as the propeller of all movements in the body inclusive of fluid circulation; as the cause of many diseases, particularly those of the nervous system; in building up the anatomy and physiology of the foetus from the moment of conception; and in the circulation of the mother's vital breath through the embryo. Apart from the pneuma theory, the Āyurvedic concept of humoral origin of diseases also occurs in Hippocratic manuals, but the treatment is less sophisticated. It is reasonable to conclude that these ideas 'were imported into Greece along with many other Āyurvedic concepts'.[84] The medical treatment of eye diseases of elephants referred to by Megasthenes (*c.* fourth century B.C.) is found to have been based on ideas borrowed from the *Hastyāyurveda* of Pālakāpya. The use of drugs like dry *pippalī* (long pepper) as a cure of eye diseases, and many other facts and logical inferences show that Āyurveda spread into Greece. Conversely, some ideas associated with Greek medicine might have been incorporated in Āyurveda.

The spread of Āyurveda in Hellenic countries is to some extent inferred, but in the case of Arab countries and other parts of the world it is evident as Āyurvedic texts or their translations are found there. Some renowned Āyurvedic texts were translated into Arabic and from Arabic into Persian. The *Suśruta-saṁhitā* was translated by an emigrant Indian physician under the title of *Kitab-Samural-hind-i*. Ali ibn Zain translated the *Caraka-saṁhitā* under the title of *Sarag*. The *Aṣṭāṅgahṛdaya* was translated as *Astankar* and the *Mādhava-nidāna* as *Badan*. Āyurveda thus came to be a well-known science in Arabia from where it spread into Persia.

There is evidence of the spread of Āyurvedic concepts and texts in Iran, Central Asia, Tibet, Indo-China, Indonesia, and Cambodia. Several Āyurvedic texts have been found in Central Asia. Mention may be made of the famous Bower MS. unearthed from Kuchi or Kucha and of the part of a bilingual MS. of *Yogaśataka* ascribed to Nāgārjuna or Vararuci.[85]

[83]P. Ray, *History of Chemistry in Ancient and Medieval India* (Indian Chemical Society, Calcutta, 1956), pp. 158-63.

[84]Majumdar, 'Medicine', *op. cit.*, p. 259.

[85]*Ibid.*, pp. 257-62.

12

AGRICULTURE IN ANCIENT AND MEDIEVAL INDIA

AGRICULTURE came to be practised when man gave up his nomadic habits and settled in favourable climate and topography. Initially depending on wild roots, fruits, and seeds for his sustenance, man eventually adopted the practice of tilling the land to grow crops. The process of evolution from the nomadic to the farming stage was slow, and the ancient man undoubtedly had to learn many things by trial and error. From the coarse elementary stone implement was developed the ploughshare to till the soil. That crops would respond to the use of manure like cow-dung or decomposed plant material perhaps dawned on the ancient farmer only by chance. Animals were initially killed for their flesh and skin, but it came to be realized that they had uses for farming as well. Thus began the domestication of animals.

Although it has not been ascertained when the early inhabitants of India took to farming as their chief occupation, the practice of agriculture has been traced back to the Indus valley civilization. Thus, for at least the last 4,500 years the Indian society has been primarily an agricultural one. The variety of topography and climate of the subcontinent has afforded a great diversity in the crops cultivated in different regions. Moreover, the country possesses vast arable land. Indeed, India's agricultural wealth in terms of variety and production has significantly influenced the course of her history.

PRE-VEDIC PERIOD

The Indus valley civilization was one of the earliest civilizations of the world. Agriculture, besides being extensive, was the corner-stone of its economy. The soil of the valley was alluvial and fertile. Although no definite information is available as to the actual method of cultivation in vogue in those days, it seems likely that a toothed harrow, which is apparently depicted on one of the Indus script ideograms, served the purpose of the plough. The discovery, again, of some stone implements 'much too heavy to have served as weapons' suggests that these were ploughshares 'quite efficient in the stoneless alluvial soil of the Indus plains'.[1] Two incomplete curved blades of copper recovered from Mohenjo-daro were probably used as sickles for harvesting purposes.

Agriculture depended partly on rainfall and partly on flood irrigation. Among the crops cultivated were wheat, barley, field peas, lentils, flax, and cotton, while melon and date were among the fruits grown. The wheat un-

[1]Ernest Mackay, *Early Indus Civilization* (Luzac and Company, London, 1948), p. 132.

earthed at Mohenjo-daro belongs to *Triticum vulgare* and *Triticum compactum*, and that from Harappa to the dwarf variety, *Triticum sphaerococcum*. Some of these varieties are still cultivated in the Punjab. The discovery of charred rice grains at Rangpur and Lothal in Gujarat suggests that rice was used in India around 2000 B.C. This is the oldest record of the use of rice in the world.[2]

Information on animal husbandry in the pre-Vedic period is as scanty as that on agriculture. However, the figure of a bull on a Mohenjo-daro seal is interpreted as indicating that great importance was attached to cattle breeding in those days. The skeletal remains of the humped bull, buffalo, sheep, elephant, and camel unearthed in the Indus valley area show that these animals were domesticated.

VEDIC PERIOD

In the Vedic period agriculture was the chief occupation of the people. The term *kṛṣi* (ploughing) occurs in the *Ṛg-Veda* quite a number of times,[3] indicating their familiarity with cultivation. It mentions sowing of grain by means of the plough (I.117.21), which appears to be an improvement upon the toothed harrow or the ploughshare of the Indus valley civilization. The plough was drawn by oxen in teams of six, eight, or twelve. The *Ṛg-Veda* (I.100.18, 127.6; IV.41.6) refers to arable land as *urvarā* or *kṣetra*. Mention is made of the use of manure (*śakan, karīṣa*). The importance of irrigation was recognized. Ancient Indian cultivators used to conserve rain-water in tanks and reservoirs and sought to supplement it by digging wells. According to the *Ṛg-Veda* (X.101.6), well-water was raised by means of a strap and water pail. Another method employed a number of pots tied to a rope which moved over a revolving wheel (X.93.13). There is mention in the *Ṛg-Veda* (X.101.7) of an apparatus which involved the operation of a wheel made of stone (*aśma-cakra*) for lifting water from a well (*avata*). This text also refers to other contrivances for lifting water from wells and lakes.

References to a few food grains are found in the *Ṛg-Veda*. These include *yava* (barley), *tokman* (oats), and *dhānya* (a common name for all food grains). Rice (*vrīhi*) is not mentioned in the *Ṛg-Veda*. Rotation of crops and fallowing of the land to restore its fertility are prescribed by the *Ṛg-Veda* (VIII.91.5-6). According to some scholars, a verse in the text (X.131.2) gives an idea of the practice of crop sequence, line-sowing, and harvesting. The *Śatapatha Brāhmaṇa* (I.6.1.3) clearly sums up agricultural operations as 'plou hing, sowing, reaping, and threshing'. The ripe grain used to be cut with a sickle, bound in bundles, and beaten out on the floor of the granary. The grain was finally separated

[2] K. A. Chowdhury, 'Plant Remains from Pre- and Proto-Historic Sites and Their Scientific Significance', *Science and Culture*, XXXI, No. 4 (1965), p. 177.

[3] I. 23.15, 176.2; X. 34.13, 117.7; etc.

from the straw and refuse. A hymn of the *Ṛg-Veda* (X.27.8) in praise of land, bullocks, seeds, and peasants indicates the importance attached to crop husbandry with different types of field grasses for food and fodder.

The *Yajur-Veda* mentions twelve grains: (i) *vrīhi*, (ii) *nīvāra* (a form of wild rice), (iii) *yava*, (iv) *godhūma* (wheat), (v) *priyaṅgu* (a kind of small millet), (vi) *aṇu* (another kind of millet), (vii) *śyāmāka* (*śyāmā* grass), (viii) *māṣa* (pulse), (ix) *mudga* (pulse), (x) *masūra* (lentil), (xi) *khalva* (perhaps a wild grain), and (xii) *tila* (sesamum). The word *ikṣu* (sugar-cane) is found in the *Taittirīya Saṁhitā* (VII.3.16) and *Atharva-Veda* (I.34.5). It is not certain, however, whether sugar-cane was cultivated or grew wild.

A passage in the *Taittirīya Saṁhitā* (VII.2.10.2) discusses the seasons of agriculture. Barley, for instance, is stated to ripen in summer, rice in autumn, beans and sesamum in winter. It is mentioned that in the course of a year two crops are harvested from the same field (V.1.7.3). The *Atharva-Veda* has several passages on farming and the use of manure.[4] It also speaks of specific crop problems such as damage caused by insects and animals, excessive rain, and drought, and recommends charms to prevent such calamities (VI.50.1-2; VII.11).

Vedic literature is replete with references to domesticated animals, particularly the cow or ox (*go*). In Vedic India the cow was a major source and measure of wealth and one of the standards of exchange. Large herds of cattle were common. Cow's milk (*kṣīra*) was processed into clarified butter (*ghṛta*) or curd (*dadhi*) and was an important ingredient of daily diet as well as Vedic sacrifice. The *Taittirīya Saṁhitā* (VII.5.3.1) mentions that cows were milked thrice daily: morning, forenoon, and evening. The first milking provided considerable milk, the later two milkings less. The flesh (*māṁsa*) of both cows and bulls was sometimes eaten. Oxen or bullocks were used for ploughing and drawing carts and wagons. The *Ṛg-Veda* (I. 62.9) notes that the cattle were red (*rohita*), light (*śukra*), dappled (*pṛśni*), or black (*kṛṣṇa*) in colour. Ownership of cattle was indicated by markings made on the cattle's ears. The herds were tended by a herdsman (*gopa*, *gopāla*) while in the fields.

POST-VEDIC PERIOD

Post-Vedic literature provides more detailed information on agriculture in its different aspects: land and soil, manure, tillage, crops and seeds, irrigation, protection of crops from diseases and pests, and animal husbandry.

Land and Soil: Pāṇini (*c.* fifth century B.C.) in his *Aṣṭādhyāyī* speaks of cultivated land (*karṣa*) and two kinds of uncultivated land, viz. *ūṣara* (wasteland) and *gocara* (pasture). Classification of land was also made at this period on the

[4] II. 4.5, 8.3; VI. 91.1; VIII. 2.19; X. 6.12; etc.

basis of the crops grown and the quantities of seed required for sowing. In this regard, the land where *śāli* is grown is termed *śaileya*; similarly, the land which grows *tila* is called *tilya*; that growing *vrīhi vraiheya*; and so on. He also prescribes the quantity of seeds required to be sown on a given measure of land. By the time of Kauṭilya (*c.* 320 B.C.) people appear to have developed an awareness of the agricultural properties of land. According to his *Arthaśāstra*, land could be *kṛṣṭa* (cultivated), *akṛṣṭa* (uncultivated), *sthala* (high and dry ground), *kedāra* (field sown with crops), *mūlavāpa* (field for growing roots), and so on. He also classifies various regions according to annual rainfall. Patañjali (*c.* second century B.C.) in his *Mahābhāṣya* (III.3.119) refers to arable land (*kṣetra*) and pasture (*gocara*). Land under the plough is described as *halya* or *sītya* (I. 1.72).

Both Suśruta and Caraka, belonging to the first century A.D., divide land into three general classes, viz. *jāṅgala* (barren), *anūpa* (moist), and *sādhāraṇa* (ordinary). Exposed to gusts of dry wind, *jāṅgala* land has a flat surface with scanty growth of scattered thorny bushes. *Anūpa* land consists mostly of marshy or swampy areas thickly overgrown with forest trees. *Sādhāraṇa* land abounds with creepers, plants, and trees. In addition, they make classifications based on the capacity of the land to yield plants of medicinal value. The *Suśruta-saṁhitā* (I.37.2) states that the best soil for growing medicinal herbs and plants is one which is 'glossy, firm, black, yellowish or red and does not contain any sand, potash, or any other alkaline substance'.

The *Kāśyapīya-kṛṣisūkti* of unknown date attributed to Kāśyapa speaks of five kinds of land, namely, *brāhmaṇa*, *kṣatriya*, *vaiśya*, *śūdra*, and land of mixed qualities.[5] Another classification of the post-Vedic period was on the basis of the productivity, rainfall or inundation, and terrain of the land. Classifications were also made according to the colour of the soil, namely, grey, black, white, red, or yellow; taste of the soil, namely, sweet, sour, bitter, or pungent; and its texture, stony or soft. It was known that the best soil was dark in colour, full of organic matter, and in the proximity of water. Wet lands were considered suitable for the cultivation of paddy and dry lands for other crops.

Manure: Manuring was widely practised in the post-Vedic period. Kauṭilya (II. 24) mentions bone and cow-dung as manure. He also recommends that seedlings should be manured with fry and the milk of the *snuhi* plant (*Euphorbia antiquorum*). The *Bṛhat-saṁhitā* (*c.* sixth century A.D.) and the *Agni Purāṇa* (*c.* eighth century A.D.) refer to the application of such manure as animal excreta, fish, bone, beef, and various kinds of decoction. The *Bṛhat-saṁhitā* describes in detail how seeds should be soaked in specially prepared solutions and how they should be treated before they are sown. The *Agni Purāṇa* says

[5]See *Agriculture in Ancient India*, ed. D. Raghavan (Indian Council of Agricultural Research, Delhi, 1964). p. 5.

that the soil should be manured with powdered barley, sesamum, and the offal matter of goats, and soaked in washings of beef for seven nights at a stretch. Sprinkling of the washings of fish on the seeds is also recommended. The knowledge in respect of manure in those days was obviously the result of practical observations. It is now known that the loss of nitrogen from a dung-heap is minimized if the heap is kept undisturbed. It is significant that Parāśara in his *Kṛṣi-parāśara* (*c.* A.D. 950) also advises that a dung-heap should remain undisturbed up to the month of Māgha (January-February), i.e. for ten months of the year. The *Vṛkṣāyurveda* (*c.* tenth century A.D.) by Surapāla has numerous references to manure and the process of manuring. Milk and extracts of cereals and pulse, apart from animal excreta, are considered efficacious in the nutrition of specific crops and various plants and trees. The *Śukranīti* (*c.* fourteenth to sixteenth century A.D.) states that for healthy growth a plant should be nourished by water, meat, and the excreta of goats, sheep, and cows. The *Śukranīti* also speaks of the application of water mixed with barley, sesamum, and the excreta of goats and sheep to the roots of plants. If the solution is applied after it is kept for seven days, the *Śukranīti* says, it promotes the growth of flowers and fruits.

Tillage: The plough has been one of the symbols of the material evolution of India. It was known in the post-Vedic period that one ploughing gave a fair result in terms of crops, two ploughings a better one, while the best result was obtained if the land was ploughed five times. The *Arthaśāstra* (II.24) speaks of preparing the fields by ploughing three times in heavy rains. Deep ploughing is also mentioned. Patañjali in his *Mahābhāṣya* refers to ploughing being done with the help of oxen (V. 3.35). It appears from the *Mahābhāṣya* (III. 3.83) that weeds, thorns, and stones used to be removed by a hoe (*stambaghna*) before the ploughing. The number of ploughs employed for tilling a piece of land depended upon various factors like its fertility and dimension. The maximum number mentioned in the *Mahābhāṣya* in this respect is five.

The *Amarakoṣa* (*c.*. A.D. 500) lists a number of agricultural implements and accessories which must have been in use in the post-Vedic period. Among these are *lāṅgala* or *hala* (plough), *yoktra* (tie for fastening the yoke to the plough), *prājana* or *toḍana* (goad), *kotiśa* (harrow), *khanitra* (spade or hoe), and *dātra* or *lavitra* (sickle). A detailed description of the plough is found in the *Kṛṣi-parāśara* (110-117). The plough, the text says, comprises the following parts: *yuga* (yoke), *aḍḍacalla* (pins of the yoke), *īṣa* (pole of the plough), *niryola* (a wooden pole at the end of which the plough is fixed), *śaula* (an extra piece of wood which firmly fixes the *niryola*), *niryolapāśikā* (plates), *halasthāṇu* (a piece of wood fixed to the *niryola* at the end opposite to that of the ploughshare), *paccanī* (a goad made of bamboo with an iron top), *abandha* (iron rod which prevents the *niryola* from getting out of its position), *yoktra* (tie), and

phāla (ploughshare). The choice of size and shape of the plough depended on several factors such as the nature of the soil, sub-soil, crop, season, and manure. Thus in the post-Vedic period different forms of plough were in use, some of which are still to be seen in parts of the country. In addition to enumerating the parts of the plough, the *Kṛṣi-parāśara* mentions the following agricultural accessories: *sṛṇi* (sickle), *khanitra* (hoe), *muṣala* (pestle), *śūrpa* (winnowing basket), *dhānyakṛt* (winnowing fan), *cālanī* (sieve), and *methi* (threshing post).

Crops and Seeds: The *Arthaśāstra* (II.24) speaks of raising three crops a year—one sown in the rainy season and harvested in Māgha (January-February); the second sown in autumn and collected before Caitra (March-April); and the third sown in spring and cropped by Jyaiṣṭha (May-June). The crops to be sown in each season are enumerated as follows: '*Śāli* (a kind of rice), *vrīhi* (rice), *kodrava* (*Paspalum scrobiculatum*), *tila* (sesamum), *priyaṅgu* (panic seeds), *daraka* (?), and *varaka* (*Phraseolus trilobus*) are to be sown at the commencement (*purvāvāpaḥ*) of the rainy season. *Mudga* (*Phraseolus mungo*), *māṣa* (*Phraseolus radiatus*), and *śaimbya* (leguminous crop) are to be sown in the middle of the season. *Kusumbha* (safflower), *masūra* (*Ervum hirsutum*), *kulattha* (*Dolichos uniflorus*), *yava* (barley), *godhūma* (wheat), *kalāya* (leguminous seeds), *atasī* (linseed), and *sarṣapa* (mustard) are to be sown last.'[6] The *Arthaśāstra* is practical in its prescription, however, when it enjoins that seeds may be sown earlier or later if the seasons do not follow their normal patterns. Lands suitable for growing vegetables and fruits such as *vallīphala* (pumpkin, gourd, etc.) and *mṛdvīkā* (grapes) are also mentioned. It further says that marginal furrows between any two rows of crops are suitable for the sowing of fragrant plants, medicinal herbs, cascus roots, etc. (II.24). Regarding seed treatment, the treatise lays down that 'the seeds of grains are to be exposed to mist and heat for seven nights; the seeds of *koṣī* are treated similarly for three nights; the seeds of sugar-cane and the like are plastered at the cut end with a mixture of honey, clarified butter, the fat of hogs, and cow-dung; the seeds of bulbous roots with honey and clarified butter; cotton seeds with cow-dung....'[7]

Patañjali's *Mahābhāṣya* (II.3.19) makes reference to some important crops and discusses the mixed cropping of sesamum with beans as the main crop. The seeds of the second crop are to be sown broadcast while the land is to be prepared to suit the main crop.

The *Kṛṣi-parāśara* discusses the proper care of seeds. They should be collected in Māgha (January-February) or Phālguna (February-March). After exposure to the sun and night dew, they should be carefully stored in containers made

[6] *Kauṭilya's Arthaśāstra*, trans. R. Shamasastry (Mysore, 1951), p. 128.
[7] *Ibid.*, pp. 129-30.

of straw. Care should be taken that the different varieties of seeds are not mixed. Neither should they come in contact with ghee, oil, or salt. This last advice is probably based on the knowledge that acid and salt solutions destroy the germinating power of seeds and fats retard it.

Many kinds of crops are discussed in the *Kāśyapīya-kṛṣisūkti*.[8] Rice is considered to be the most important among them, followed by pulse, then vegetables, and lastly dairy produce. Rice is classified into three general kinds according to colour and flavour: *śāli*, *kalama*, and *ṣaṣṭhika*. *Śāli* rice is of twenty-six varieties depending on the region where it is grown and the soil conditions. *Kalama* rice is bright, aromatic, and somewhat hard. *Ṣaṣṭhika* rice is without flavour. The entire procedure of rice cultivation is treated in this work, including all the important steps and precautionary measures to be taken. Among other grains discussed are pulse, sesamum, wheat, mustard, and barley. Vegetable crops mentioned include cucumber, eggplant, gourd, chilli, and pumpkin. Spices like turmeric, ginger, cardamom, pepper, and coriander are included in the discussion. The fruits dealt with are mango, grapes, date, coconut, banana, bread-fruit, and rose-apple among others. Kāśyapa recommends the cultivation of sugar-cane because of its bushy growth, yield of jaggery and sugar, and suitability as food for elephants.

The proper collection, preservation, and sowing of seeds are essential to ensure an adequate crop the following year. The *Kāśyapīya-kṛṣisūkti*, therefore, devotes considerable space to discussing this important aspect of agriculture. The principle of transplanting seedlings is also laid down. For instance, it recommends that the seeds of eggplant, after being dried in the sun, should be sown in soil dressed with cow-dung and then watered regularly. After the sprout appears and takes firm root, which requires about twenty days, it should be transplanted to a properly prepared field.

Kālidāsa (*c.* fifth century A.D.) in his *Raghuvaṁśa* refers to the growing of paddy in Bengal. The *Amarakoṣa* mentions crops like cucumber, pumpkin, onion, and gourd. Surapāla (*c.* tenth century A.D.) in his *Vṛkṣāyurveda* speaks of crops like barley, wheat, rice, maize, millet, *bājri* (a kind of cereal), sesamum, mustard, linseed, cotton, and various pulse. He prescribes specific seed rates per *bighā* (a third of an acre) in respect of these crops. There is a detailed description in his book of fruit trees and flowering creepers. He advises cultivators about the appropriate time for sowing seeds and the spacing of plants.

Irrigation: Irrigation methods and facilities were further developed in the post-Vedic period. An example of the importance attached to irrigation is provided by lake Sudarśana of Kathiawar in Gujarat, caused to be excavated by Puṣyagupta (*c.* fourth-third century B.C.), and by its irrigation canals

[8]See *Agriculture in Ancient India*, pp. 62ff.

completed in Aśoka's time (*c.* third century B.C.). The lake measures approximately 630′ × 630′. The principle of constructing canals to draw water to distant fields from the catchment areas of hills and undulating areas was known. Sluices were utilized in the canals to control the flow of water. Patañjali (I.1.23) notes that periodic watering (irrigation) of the fields is necessary for the growth of crops and apparently suggests that canals should be employed for this purpose (*śālyārthaṁ kulyāḥ praṇīyante*). The *Nārada-smṛti* (*c.* third century A.D.) mentions two classes of dykes or water courses, namely, *kheya* and *bandhya* (XI.18). The first, dug into the ground, served the purpose of irrigation, while the object of the second kind was to prevent water from flowing out.

The *Kāśyapīya-kṛṣisūkti* provides much information on the excavation, maintenance, and utilization of reservoirs, canals, and wells.[9] It says that reservoirs should be excavated near a hill or on flat land. They may be fed by a big lake, big river, forest stream, or rivulet. They should be deep, have high embankments, be strongly reinforced for protection against breakage, and be furnished with a causeway, flood-gates, and channels. Additional channels should be dug during the rainy season to carry away the increased flow of water. The reservoirs should be inspected regularly. Canals should be dug to carry water to the fields when a perennial source of water above the field level is available. The canal should terminate in a lake or reservoir, or if that is not possible then in the fields. It should be either four, five, six, seven, or ten *hastas* in width (1 *hasta* ½′). Excessively sandy or rocky areas where water is likely to leach away should be avoided for the excavation of canals. In localities where no water source for canals is to be found or where the sources dry up or fall in level during the summer months, wells should be dug. After a proper place for the well has been determined by a diviner, digging should commence at an auspicious hour. When a level is reached where water mixed with sand is encountered, the base should be constructed. Burnt bricks are used when the stratum consists primarily of sand, and stone slabs when it is of firm texture. The sides are to be constructed with bricks and mortar. If necessary, steps should be provided. Provision should be made at the top of the well for attaching a water-raising device.

Protection of Crops from Diseases and Pests: Crop protection in the modern sense of the term had not developed much in the early post-Vedic period because of the lack of knowledge about the remedial chemicals. Reference to the destruction of paddy crops by mildew attack occurs in the Buddhist text *Cullavagga* (X. 1.6), which also speaks of the 'blight' disease of the sugarcane crop. But there is no mention of the remedy. References to the need for protection of crops from damage caused by animals and birds are found in Patañjali's *Mahābhāṣya*. It appears that observers used to be posted in

[9] *Ibid.*, pp. 19ff.

order to keep deer away from the vicinity of barley fields (I. 1.3, 39). The text (I. 2.52) also speaks of scarecrows made of straw (*cañcābhirūpāḥ*) being placed in crop fields with a view to frightening away birds—a practice still in vogue. Miśra Cakrapāṇi in his *Viśvavallabha* of unknown date recommends medicines to destroy vermin that cause damage to crops.[10] The medicines referred to are of several kinds such as those emitting offensive smell and those having acrid taste.

The *Vṛkṣāyurveda* of Surapāla classifies plant diseases into (i) those arising internally and (ii) those infecting the plant from outside sources. The internally affected diseases are thought to stem from a disturbance in the equilibrium of the *vāta*, *pitta*, and *kapha*, or basic metabolism, of the plant. Externally caused infection is said to arise from inclement weather conditions and pests. Various decoctions are prescribed as remedies for diseases, insect infestation, and damage to plants. For instance, one suggested cure for diseases arising from an imbalance of *vāta* is to apply flesh, lymph fat, and ghee in an attempt to strengthen the natural vitality of the plant. A remedy recommended for killing insects is to apply water containing cow-dung, *vaca* (a kind of aromatic root), carcass, and milk, and a plaster prepared from *vaca*, *kuṣṭha*, (a kind of plant), *ativiṣā* (a poisonous medicinal plant), *mustā* grass, and white mustard. The text further states that trees and plants must be carefully protected from heat and frost. The only remedy suggested for trees eaten by vermin, burnt by fire, broken by storms, or struck by lightning is to cut off the affected parts. Moreover, if the affected tree be smeared with the paste of cow's urine, ghee, mustard, and sesamum, sprinkled with diluted milk, and fumigated with burning incense, the recovery is found to be rapid.

Animal Husbandry: In the post-Vedic period great importance was attached to animal husbandry. There are several references in the *Mahābhārata* to animals like the cow, horse, and elephant. These were used for various purposes and must have been tended with care. Kauṭilya's *Arthaśāstra* has sections dealing with the duties of the superintendents of cows, horses, and elephants. The *Mahābhāṣya* of Patañjali contains some information regarding different kinds of cows, the method of controlling them at the time of their grazing, and their stables (*śālās*). The two words *gopālaka* (I. 1.23) and *gopālikā* (IV. 1.78) suggest that both men and women used to tend cows. Patañjali mentions *gopāḥ* (persons in charge of cattle) as a special *jāti* or class (III. 1.31).

Although veterinary science was not much advanced during this time, its importance was well known. Certain sanitary measures and various kinds of treatment for diseases and physical disorders were employed. The *Agni Purāṇa* speaks of measures to guard against the outbreak of cattle diseases due to unhygienic conditions of sheds. It says that the shed should be fumigated

[10] *Ibid.*, p. 88.

from time to time 'with the vapours of *devadāru* (*Pimus deodara*), *vaca*, *māṁsī* (pulp of some fruit), *guggulu* (a fragrant gum resin), *hiṅg* (asafoetida), and mustard seeds mixed together' (CCXCII. 33). The *Viṣṇudharmottara Purāṇa* (supposed to have been compiled between *c.* A.D. 450 and 650) mentions certain methods of treatment for curing cattle diseases affecting the horns, teeth, throat, eyes, etc. and for other physical disorders (II. 43.1-27). The text speaks of a kind of oil which should be applied with rock-salt and honey to the roots of the affected horns. According to this *Purāṇa*, the powder of the roots of wood-apple tree, *apāmārga* (a kind of plant), *paṭala* (a kind of tree), and *kuṭaja* (a kind of tree) when rubbed into the gums removes toothache. Ginger, turmeric, and myrobalans are said to cure sore throat, while collyrium prepared in a particular process is recommended for some eye ailments. *Priyaṅgu* (a kind of creeper) mixed with salt is stated to help in the reunion of fractured bones. For bilious disorders the administration of ghee made of cow's milk in which liquorice has been cooked is suggested. Milk mixed with turmeric is recommended as a drink for ailing calves. Oil-cake is considered to be a nourishing food for cattle. Common salt is recommended to be mixed with the fodder once in fifteen days in order to prevent general stomach disorders. The *Kṛṣi-parāśara* (84-88) gives a number of rules for tending cattle and lays stress on cowsheds being kept clean. It prescribes the size of a shed good for the healthy growth of cattle and points out that 'the washing of rice, hot scum of the boiled rice, fish broth, cotton seeds and husk, if kept in the cowshed, prove baneful to the cattle' (89-92). The text also mentions that almost every village possessed common pasture, woodlands, and stores of drinking water for domestic animals.

MEDIEVAL PERIOD

Although farming methods in the medieval period remained much the same as before, considerable progress was made in the introduction of new crops and the improvement of some old ones. One of the important new crops was the cashew introduced from South America in the sixteenth century. The cashew has subsequently proved to be a valuable cash crop. Other crops introduced were the pineapple, potato, guava, and custard apple. Tobacco, papaya, and a variety of chilli (*Capsicum frutescens* L) first appeared in India at this time also. Coffee was introduced in India probably soon after Akbar's time (1556-1605). The yield from the cotton crop seems to have increased to a great extent in the thirteenth and fourteenth centuries. The Italian traveller Marco Polo speaks of extensive cotton cultivation in India. Pepper, ginger, and indigo were also widely cultivated. The Jesuits of Goa introduced systematic mango grafting in the late sixteenth century which greatly improved the quality of the fruit.

Agriculture in Mogul India was on a par with contemporary practices elsewhere.[11] According to Fryer, the system of cultivation in the coastal areas was not remarkably different from that practised by other nations.[12] He notes that the ploughshares were mostly wooden as iron was scarce, but the hard wood used for the purpose was sufficient to turn light ground. For the drier and harder soils inland, however, iron ploughshares were in use. Drill-sowing and dibbling were familiar agricultural practices of the time. The system of feeding the soil with bone manure was not known, but the value of fish as a fertilizer was understood. The practice of growing more than one crop from the soil was fairly common in some areas. The system of rotation of crops was so planned that the exhaustion of the soil due to growing one crop could be made good by the cultivation of a second crop. The excavation of tanks and canals, considered a meritorious act, continued in this period. Among the notable ones is Shāh Jahān's (1628-58) *Nahr-i-Bihist* or *Shah Nahr*, a canal about 78 miles in length constructed to bring water to his newly built city of Shāhjahānābād in Delhi.

The importance of animal husbandry to the agrarian economy of India was fully realized during the Mogul period. Land for the grazing of cattle was available in plenty. Bengal had vast pastures for grazing large herds of cattle. Abū'l-Fazl mentions that the number of tax-free cattle allowed per plough was four bullocks, two cows, and one buffalo. The number of milch cattle per head of population was also large as is evident from the plentiful availability of clarified butter or ghee in the country.

The vast majority of Indians from ancient times have lived in countless villages tilling the land for their sustenance. This condition still prevails in the modern age. The kind of agriculture that has been in vogue over the centuries can be described as a combination of common sense and practical experience based on sound scientific principles, although these may not have been understood by most farmers. The pithy sayings relating to agriculture which are common in rural India testify to the knowledgeable insight which has always dominated Indian farming.

[11]Irfan Habib, *The Agrarian System of Mughal India* (Asia Publishing House, Bombay, 1963), p. 25.

[12]John Fryer, *A New Account of East India and Persia Being Nine Years' Travels, 1672-81*, ed. W. Crooke, 3 Vols. (Hakluyt Society, London, 1909, 1912, and 1915).

13

MINING IN ANCIENT AND MEDIEVAL INDIA

MINING is basically a technical process to extract raw materials from the earth. The nature of the raw material to be extracted greatly determines the technical process to be applied. The basic issue is to trace the development of these technical processes in their historical perspective. Unfortunately this is a task which is difficult to accomplish for ancient and medieval India. Firstly, we do not have detailed textual information on the technical processes, and what we have hardly goes beyond general references to mining. Secondly, no ancient mine has yet been subjected to a proper archaeological investigation. One does not really *excavate* an ancient mine, but one may very well clear an ancient mine-shaft, look for datable antiquities in the debris, and try to obtain some samples for purposes of dating (cf. Carbon-14 dating). There are, in fact, a few Carbon-14 dates from some old workings in India but the number of such dates is still very limited. Archaeological data are, however, clear on the growth of metallurgy in India, thus indirectly revealing the basic antiquity of different mining activities in the country. Through a wide application of the techniques of ore-artifact correlation it is, however, possible to determine, particularly in the context of copper-bronze objects, the areas which supplied ore in different periods. A limited amount of data is available, but much remains to be done.

In the absence of a firm body of literary and archaeological evidence one has to depend rather heavily on the geological and ethnographic data. The geological data are in the form of observations on the traces of old workings. These old workings very often provided the geologists with a clue to the occurrence of ores in these areas. A substantial body of such observations is available, of which the first systematic review was made by V. Ball in 1881.[1] Observations on ancient workings occur in more recent geological literature too, but these workings have never been the subject of a systematic study. Even the basic observations are hardly detailed. It is well known that even in recent mining operations traces of old shafts are quite commonly encountered, but usually no specific records are kept and published with plans of the old shafts. It is hardly necessary to add that the records and publications of plans of this kind would have been invaluable for this kind of study. The range of ethnographic data is quite limited and consists of a few nineteenth-century observations on the actual pre-industrial mining processes. It

[1]V. Ball, *Economic Geology of India*, Part III (Calcutta, 1881).

cannot, of course, be said with certainty that pre-industrial mining operations recorded in the nineteenth century really continued from ancient times, but considering the general element of continuity of pre-modern technological tradition in India, it may be assumed that these pre-industrial mining operations could not have been much different from what obtained in ancient and medieval times. The historical implications of these geological and ethnographic data in respect of copper were discussed by P. Neogi[2] as early as 1918. Much later D. Kercross[3] (1950) depended exclusively on these data for his paper on ancient mines and miners of India.

It is thus obvious that the basic sources of the history of mining in pre-industrial India are archaeological documentation on the growth of metallurgy, literary references, geological observations on the survival of old workings and their dates, and some records of pre-industrial mining operations. Each of these sources has its own limitations. In the absence of systematic research on the subject much of the present analysis can only be tentative, but even such a study is likely to bring out the broad areas where further research can be fruitful.

ARCHAEOLOGICAL EVIDENCE

Gold, silver, copper, tin, and lead were known to the Indus civilization in the third millennium B.C. The earliest record of copper is a bead found at Mehrgarh in Baluchistan and dated about 5000 B.C., but this bead could have been fashioned out of native copper and thus need not signify copper metallurgy. The knowledge of copper metallurgy is more explicit in the subsequent pre-Indus chalcolithic levels of Baluchistan and the Greater Indus valley, and at least in one such level (at Jalilpur in Multan district) there is also evidence of gold.

True bronze, an alloy of copper and tin, was known to the Indus civilization, sometimes called a Bronze Age civilization of India, although the use of bronze was somewhat limited. Sources of metals have not yet been clearly ascertained in all cases, but there is little doubt about the Rajasthan deposits of copper and lead being one of these sources. These deposits continued to be significant in the post-Indus chalcolithic stage virtually all over the country, but in many areas, particularly those away from Rajasthan, the locally available ore sources must have been exploited. The major deposits of copper and tin in East India and those of copper in Andhra belong to this category. The importance of Rajasthan in the early growth of metallurgy in India has been shown by a number of discoveries in recent years. For instance, in 1979-80 the site of Ganeshwar in the Sikar district of Rajasthan yielded about one

[2] P. Neogi, *Copper in Ancient India* (Calcutta, 1918).

[3] D. Kercross, 'Ancient Mines and Miners of India', *Indian Minerals*, Vol. IV (1950), pp. 5-10.

thousand copper objects belonging to the middle of the third millennium B.C.

The beginning of the use of iron lies somewhere in the middle of the second millennium B.C. Since iron ores suitable for pre-industrial smelting are found virtually in all areas of the country outside the Indo-Gangetic alluvium, local ore deposits were tapped. The source and extent of use of other metals in the post-Indus civilization are somewhat uncertain. Nevertheless, it is quite possible that before the beginning of the early historic period (*c.* 600 B.C.) most of the significant metal deposits of the country were known and mined. It may be emphasized that the evidence of mining is strictly circumstantial, based on the indirect evidence of the use of different metals. No ancient mine of this protohistoric period except one in the Hatti gold mining area (760 ± 150 B.C.) in Karnataka and another in the Dariba copper mining area in Rajasthan (1260 ± 160 B.C.) has been properly dated.[4]

LITERARY DATA

Literary sources support the archaeological evidence that the knowledge of gold, silver, copper, tin, lead, and iron was well established in the later Vedic period. Among the ancient texts the *Arthaśāstra* of Kauṭilya is the most significant in this regard. It recognizes the economic importance of mining when it observes that 'mines are the source of treasury'.[5] By the time of the *Arthaśāstra* mining was obviously a well-developed activity as is evident from the following duties of the Superintendent of Mines prescribed: 'Possessed of the knowledge of the science dealing with copper and other minerals, experienced in the art of distillation and condensation of mercury and of testing gems, aided by experts in minerology and equipped with mining labourers and necessary instruments, the superintendent of mines shall examine mines which, on account of their containing mineral excrement, crucibles, charcoal, and ashes, may appear to have been once exploited or which may be newly discovered on plains or mountain slopes possessing mineral ores....'[6]

[4] For recent researches on the archaeological evidence of the basic antiquity of metals see D. P. Agrawal, *The Copper-Bronze Age in India* (Delhi, 1971); Dilip K. Chakrabarti, 'The Problem of Tin in Early India', *Man and Environment*, Vol. III (1979), pp. 61-74; 'The Beginning of Iron in India', *Antiquity*, Vol. L (1976), pp. 114-24, 'Research on Early Indian Iron, 1795-1950', *The Indian Historical Review*, Vol. IV (1977), pp. 96-105, 'Distribution of Iron Ores and the Archaeological Evidence of Early Iron in India', *Journal of the Economic and Social History of the Orient*, Vol. XX (1977), pp. 166-84, 'Iron in Early Indian Literature', *Journal of the Royal Asiatic Society* (1979), pp. 22-30, and 'Early Iron Age in the Indian Northwest', *Essays in Indian Protohistory* (Delhi, 1979), pp. 347-64; M. D. N. Sahi, 'Iron at Ahar', *Essays in Indian Protohistory*, pp. 365-68; J. G. Shaffer, 'Bronze Age Iron from Afghanistan: Its Implications for South Asian Protohistory', unpublished paper presented at the Wisconsin Conference on South Asia, 1978; and F. R. Allchin, 'Upon the Methods and Antiquity of Goldmining in Ancient India', *Journal of the Economic and Social History of the Orient*, Vol. V (1962), pp. 195-211.

[5] *Kauṭilya's Arthaśāstra*, trans. R. Shamasastry (Mysore, 1956), p. 89.

[6] *Ibid.*, pp. 83-84.

What makes this passage worthy of note is its clear enumeration of the process of mineral exploration. A detailed description of different mineral ores and the methods of their purification as well as the process of softening metals follows in the text, showing interest in the classification of ores and some associated technical problems.

There are references to mines of diamond, ruby, gold, silver, copper, lead, and iron in Abū'l-Fazl's *Āin-i-Akbarī*, but virtually nothing else in this regard.[7] This may be considered fairly typical of the testimony of medieval texts in this direction. It is virtually impossible to reconstruct the technical history of mining in ancient or medieval India on the basis of texts. To say that mining was known in ancient India is not really saying very much. What one would like to know is how the technical operations of mining were conducted and how the whole process was controlled and organized. The *Arthaśāstra* throws some light on the second issue but none on the first.

GEOLOGICAL LITERATURE

Geological literature has many references to ancient mine workings encountered in the course of field-work. In the absence of positive archaeological and literary testimony these constitute about the only tangible proof of widespread mining activities in ancient, medieval, and pre-industrial India. This body of literature is voluminous, but has not been properly sorted out. The following records about a few mining sites are typical.

The Baragunda copper mine (eastern India, the Singhbhum copper belt): 'We are not in possession of any information as to who the ancients were who made the numerous excavations at Baragunda of which ample evidence is still to be seen.... Along the main line the width of the excavations averages from 25 to 30 yards. The miners appear to have thrown the debris behind them as they progressed, the depth to which they could go being limited; thus there are a succession of basin-like pits separated from one another by mounds of debris, and bounded by the faces of rocks which form the foot and roof of the deposit... it seems to be legitimate to conclude that this deposit was worked for many years, and that it was only relinquished when the readily accessible part of the back of the lode had been exhausted, and when the native miners found themselves unable to cope with the difficulties arising from having to go to greater depths.'[8]

The Mosabani copper mine (eastern India, the Singhbhum copper belt): 'One of the stopes at the south end of no. 1 level, Mosabani mine broke through into an ancient working, about 60 feet (vertically) from the surface. The working is about 4 feet wide across the lode but extended for only a short distance

[7] *Āin-i-Akbarī*, trans. H. S. Jarett, Vol. III (Royal Asiatic Society of Bengal, Calcutta, 1948), p. 10.

[8] Ball, *op. cit.*, p. 254.

along it, as this point was, of course, the bottom of the ancient workings. After breaking through, old rotten timber was found, fragments 5 to 6 inches in diameter. Timbering was not a usual practice of the ancients, pillars being normally left to hold up the hanging wall....Occasionally their tools and some utensils (frequently made of soapstone as well as pottery) have been found in the workings.'[9]

It is unfortunate that the pieces or timber or utensils of soapstone and pottery found in the Mosabani mine were not preserved. Otherwise, it would have been possible to date this particular old working.

The Agnigundala copper mine (Guntur district, Andhra Pradesh): 'The ancient mining activity is revealed mostly by old workings of the nature of long, open trenches following the lodes in the direction of the strike. Some of these workings, which are accessible today, have reached a depth of 100 feet or more from the surface in the direction of the dip of the lode.'[10]

The Wynad goldfields (South India): According to Ball, these mines indicate varying degrees of knowledge of mining techniques—quarrying on the outcrops of veins, vertical shafts, adits, vertical shafts with adits, and shafts on underlie. He writes: 'Among these the most remarkable are the vertical shafts. They are, even when in solid quartz, sometimes 70 feet deep, with smooth and quite plumb sides. What the tools were which enabled the miners to produce such work in hard dense quartz no one appears able to suggest. The fragments of stone obtained from the various mines were pounded with hand-mullers, the pounding places being still seen, and the pounded stone was then, it is believed, washed in a wooden dish and treated with mercury.'[11]

The Gavulabhavi lead deposit (Cuddapah district, Andhra Pradesh): 'The ancient workings consist of linear pits and trenches, shafts and inclines developed laterally underground in the form of drifts and stopes dipping at steep angles to the east in the eastern part and to the west in the western part. One of the surface diggings extends for about 280 m. along the strike. The main underground mine had been developed for a length of over 100 m., the initial 30 m. being a partly stoped drive, followed by two parallel drives interspersed with stopes and connected by crosscuts at regular intervals. The deepest accessible stope in the mine is approximately 50 m. below the surface. Small workings in the form of trial pits and trenches are also noticed in the dolomite, mainly in the northern part.'[12]

[9]J. A. Dunn, 'The Mineral Deposits of Eastern Singhbhum and Surrounding Areas', *Memoir of the Geological Survey of India*, Vol. LXIX, Part I (1937), p. 55.

[10]M. Ziauddin, 'Ancient Copper Mining and Metallurgy Near Agnigundala, Andhra State', *Indian Minerals*, Vol. XV (1961), p. 119.

[11]Ball, *op. cit.*, pp. 182-83.

[12]B. B. Rao and K. S. Rao, 'Lead Deposits in Varikunta-Zangamrajupalle Belt, Cuddapah District, Andhra Pradesh', *Geological Survey of India Miscellaneous Publication No. 27* (1977), p. 91.

The copper workings in Kulu (Himachal Pradesh): 'In Naraul-Chashani-Danala area several old workings have been recorded.... Extensive slag heaps have been found... which suggests large scale extraction of the metal by the ancient people.'[13]

These records selected at random convey a general idea of this type of geological record, but suffer from two limitations. Firstly, the old workings are not studied and documented in detail. The references to them are only incidental in the broader context of geological research proper. Secondly, no attempt has been made to date them on the basis of objects that might have been found in the old workings. Only recently has some effort been made to obtain Carbon-14 dates from old workings, but considering the number and geographical spread of the old workings the number of dates available is inadequate.

CARBON-14 DATES

The following dates assigned to old workings are based on the half-life of 5730 ± 40 years and uncalibrated.[14]

Sample No.	Site	Date
TF-373	Mailaram, Khammam district (Andhra Pradesh), mine not specified	1415 ± 90 A.D.
TF-805	Bandlomattu Hill, Guntur district (Andhra Pradesh), mine not specified but presumably copper	50 ± 80 A.D.
TF-806	Bandlomattu Hill, Guntur district (Andhra Pradesh), mine not specified but presumably copper	1215 ± 90 A.D.
TF-1117	Dariba, Udaipur district (Rajasthan), copper working	360 ± 105 B.C.
TF-1199	Kolar gold-field (Karnataka)	690 ± 85 A.D.
TF-1221	Kumbaria, Banaskantha district (Gujarat), mine not specified	1415 ± 90 A.D.

[13]V. P. Sharma, 'On the Sulphide Mineralisation in Kulu District', *ibid.*, p. 158.

[14]The Carbon-14 dates have been compiled from the following publications: D. P. Agrawal and S. Kusumgar, 'Tata Institute Radiocarbon Date List XI', *Radiocarbon*, Vol. XVII (1975), pp. 219-25; D. P. Agrawal *et al*, 'Ancient Copper Workings: Some New 14C Dates', *Indian Journal of History of Science*, Vol. XI, No. 2 (1976), pp. 133-36; *PRL C-14 date list* 5/77 (cyclostyled); D. P. Agrawal *et al*, 'Physical Research Laboratory Radiocarbon Dates', *Current Science*, Vol. XLVII (1978), pp. 607-10.

Sample No.	Site	Date
TF-1222	Kumbaria, Banaskantha district (Gujarat), mine not specified	1045 ± 85 A.D.
PRL-53	Ambamata, Banaskantha district (Gujarat), copper working	160 ±200 B.C.
PRL-66	Ambamata, Banaskantha district (Gujarat), copper working	1100 ±100 A.D.
PRL-208 (a)	Dariba (Rajpura), Udaipur district (Rajasthan), mine not specified but presumably copper	250 ±100 B.C.
PRL-208 (b)	Dariba (Rajpura), Udaipur district (Rajasthan), mine not specified but presumably copper	1260 ±160 B.C.
PRL-210	Dariba (Rajpura), Udaipur district (Rajasthan), mine not specified but presumably copper	110 ±130 A.D.
PRL-252	Ingaladhal, Chitradurga district (Karnataka)	220 ±110 A.D.
PRL-253	Hatti, Kolar gold-field (Karnataka)	760 ±150 B.C.
PRL-254	Kaladgi, Hasan district (Karnataka), copper mine	1640 ± 80 A.D.

These dates cover a very wide period, from 1260 ±160 B.C. (PRL-208 b) to 1640 ±80 A.D. (PRL-254), although it must be emphasized that the sampling is extremely limited. Also, some mines (Dariba, Bandlomattu, Ambamata) were obviously worked for very long periods.

ETHNOGRAPHIC DATA

In the nineteenth century some mines were still being operated in the pre-industrial fashion. In certain cases observations on the working of these mines were recorded which, although limited in number, are useful in providing an insight into the basic mining operations in the pre-industrial period.

A classic paper by J. C. Brooke on the copper mines of Khetri in Rajasthan describes them as numerous shafts, giving access to galleries by which the hills were honeycombed in every direction. The shafts descended in a very irregular manner to a considerable depth. Their sides were notched and cut

in such a manner as to enable the miners to move in and out without the help of a ladder. The sections of the shafts measured about 5′×4′ or 4′×3′. A good amount of firewood (5-7 tons) was stacked on the working face of the mine and set on fire. This obviously led to the cracking of the rocks. On the third day the workers descended into the mine. Each labourer was provided with a lamp, a hammer, a mining chisel, and a small wicker basket. The only means of overcoming the seepage of underground water was by passing pitchers of water from hand to hand through the passages. The miners were said to be very poor.[15]

On the copper mines of Buxa in western Duars, V. Ball's observations were that the mines were magnified rabbit holes. The props to support the roof were only occasionally made use of, and the passages meandered with the course of the ore and did not exceed a yard square in dimension. In the narrower sections this dimension was reduced by half. The tools used were a hammer, a chisel set in a split bamboo, and a pick. The light was afforded by thin strips of bamboo. The ore was carried out in narrow baskets and picked, crushed, and finally pounded with a stone hammer or pounder fixed in a forked stick.[16]

One of the most evocative descriptions of a pre-industrial mine is that by S. Burnes of the salt mines in the Punjab. 'At the village of Kroru,' he says, 'five miles from Pindi Dadan Khan, we examined one of the principal mines. It opened into the hill through the red clayey formation, at a distance of about 200 feet from the base. We were conducted by a narrow gallery, sufficient to admit of one person passing another, for about 350 yards, of which fifty may be taken as actual descent. Here we entered a cavern of irregular dimensions, about a hundred feet high, excavated entirely in salt. The mineral is deposited in strata of the utmost regularity, occurring like the external rock in vertical layers.

'. . . There were upwards of a hundred persons, men, women, and children at work in the mine, and their little dim burning lamp on the sides of the cavern and its recesses shone with reflected lustre from the ruby crystals of the rock. The cavity has been excavated from the roof downwards. The salt is hard and brittle, so that it splinters when struck with the sledgehammer and pick-axe. The mine is not worked for two months in the rainy season. The miners live in villages among the hills. They have a most unhealthy complexion, but do not appear to be subject to any particular disease.'[17]

[15]J. C. Brooke, 'The Mines of Khetri in Rajputana', *Journal of the Royal Asiatic Society of Bengal*, Vol. XXXIII (1864), pp. 519-29.

[16]Ball, *op. cit.*, p. 276.

[17]S. Burnes, 'Some Account of the Salt Mines of the Punjab', *Journal of the Asiatic Society of Bengal*, Vol. I (1832), pp. 145-48.

T. J. Newbold's description of the diamond mines at Condapetta in Andhra Pradesh runs as follows: 'At Condapetta the mines are generally of a square form, and from 4 to 12 feet deep. The stratum cut through is of cotton soil, mixed with small grains of quartz, generally from 3 to 10 feet thick, which rests immediately on a bed of rolled stones of various sizes, from that of a paving stone to a nut, in which the diamonds are found, generally loose, but sometimes adherent.

'...The process of mining consists merely in digging out the rolled pebbles and gravel, and carrying them to small square reservoirs raised on mounds having their bottoms paved with stones and washing them carefully. At the foot of the mound is a clear space surrounded by heaps of refuse, where the washed gravel is again carefully spread out and examined in presence of the diamond contractors; the diamonds are easily recognized in the moist state by their peculiar lustre.

'...Dry weather is selected to carry on operations to avoid the inconvenience and expense of draining. In former days all the diamonds produced were carried for sale to Golconda.'[18]

Description of this kind are far more valuable than any medieval textual reference to the diamonds of Golconda.

CONCLUSION

The foregoing records testify to the knowledge of mining in ancient and medieval India. The basic antiquity of metals in the Indian context has been reasonably worked out by archaeologists. What is lacking, however, is information about the detailed operational techniques of mining. In this area the existing data are hopelessly inadequate. Study of old workings, preparation of their representative plans, and dating them on the basis of associated objects may fill up the information gap.

[18] T. J. Newbold, 'On the Condapetta Diamond Mines', *Journal of The Royal Asiatic Society of Bengal*, Vol. VII (1842), p. 226.

14

SHIPBUILDING IN ANCIENT AND MEDIEVAL INDIA

INDIA'S geographical position makes her eminently suited for maritime activities. The vast coast-line of the subcontinent and the wide network of navigable rivers have encouraged voyages since ancient times, calling for the making of craft and vessels. Thus shipbuilding in India has an ancient tradition. The sources for exploring this tradition and reconstructing the history of shipbuilding in India are (i) indigenous literature, (ii) archaeological finds and works of art, and (iii) accounts of foreigners.

INDUS VALLEY CIVILIZATION

Ancient Indians are known to have made long voyages on the Indian Ocean for the purpose of trade and for settlement abroad. There is evidence that the Indus valley people carried on trade with the civilizations of Egypt, Sumer, Persia, Crete, and Central Asia. That this trade must have been carried out to some extent on sea routes is suggested by seals discovered at Harappa depicting ships and anchors, which clearly demonstrate that the vessels used by the Harappans were deep-water craft. One seal discovered at Mohenjo-daro portrays a boat with an upraised bow and stern, and another shows a kind of anchor used by sea-going vessels.

The naval dock unearthed at the important Harappan city of Lothal in Gujarat further indicates the use of large sea craft. The dock measures 710 feet in length and 120 feet in width, and has a 23-foot opening on one side which was possibly the inlet channel. Lothal's position in ancient times made it well suited for both sea and river navigation. It was situated probably at the confluence of the rivers Savaramatī and Bhogava, though these rivers have since changed their courses. Topographical research indicates that Lothal was once near the Arabian Sea. Rao maintains that the skill and technical knowledge displayed in the construction of the dock 'presupposes a sound knowledge of hydrography and maritime engineering.'[1] Five anchor stones have been discovered in the dock's basin.

VEDIC PERIOD

There are references to sea voyages and sea-borne trade in Vedic texts. *Nau*, the term for 'ship', occurs in the *Ṛg-Veda* and later Saṁhitās and

[1]S. R. Rao, 'Further Excavations at Lothal', *Lalit Kala*, No. 11 (Lalit Kala Akademi, April 1962), p. 17.

Brāhmaṇas. In the *Ṛg-Veda* there are many passages which clearly indicate the existence of river and sea-going vessels. For instance, it mentions that merchants journeyed across the ocean to distant countries in pursuit of wealth (I. 48.3). One passage refers to a well-rigged ship in which Varuṇa and Vasiṣṭha sailed to mid ocean (VII. 88.3-4). Another narrates how Bhujyu, son of King Tugra, along with his followers was picked up by the twin Aśvins in their hundred-oared (*śatāritra*) boat when he was attacked in mid sea by his enemies (I. 116.3). A prayer for prosperity in distant lands is also found in the *Ṛg-Veda* (I. 97.8): 'O Lord, take us in a ship across the oceans for our well-being.' A kind of vessel called a *plava* is described in some detail (I. 24.35-36). It is said to be strongly constructed and able to withstand the battering of storms. It is also described as having 'wings', which, according to Sridharan, are perhaps some sort of archaic stabilizers.[2] The *Śatapatha Brāhmaṇa* (II. 3.3.15) refers to *nau-maṇḍa* which denotes two rudders of a ship. A clear reference to maritime navigation occurs in the *Baudhāyana Dharmasūtra* (I.2.4; II.2.2).

POST-VEDIC PERIOD

In the *Rāmāyaṇa* (II. 89. 11-16), mention is made of five hundred well-built ships which had the swastika sign, flew gay flags, displayed full sails, and were fitted with large gongs. We also find instructions being given to search for Sītā in the cities and mountains in the islands of the sea (IV. 40.25) and in the land of the Koṣakāras (IV. 40.23), which is 'generally interpreted to be no other country than China'.[3] There is also reference to Yavana-dvīpa and Suvarṇa-dvīpa, which are identified with the islands of Java and Sumatra. A passage in the *Mahābhārata* (I. 143.5-7) speaks of a boat fitted with some mechanical device (*yantra-yuktam*) and flags—a boat strong enough to withstand storms and waves (*sarva-vāta-sahām*). Another *Mahābhārata* passage (II. 28.44, 46) refers to Sahadeva going to several islands to bring inhabitants under subjection. Mention of a 'tempest-tossed and damaged vessel in a wide ocean' is made in yet another passage of the epic (VII. 1.28). From these records it may be presumed that sea-going vessels existed in India in the epic age.

The *Aṣṭādhyāyī* (IV. 3.10; VI. 3.58) makes a clear distinction between coastal island cargoes (*dvaipya*) and mid-ocean island cargoes (*dvaipa* or *dvaipaka*), suggesting considerable shipping activity in the fifth century B.C. The *Dīgha Nikāya* (*c.* fifth century B.C.) mentions the use of birds by mariners to ascertain the direction of land in sea voyages (1.222). According to Rhys Davids, this

[2] K. Sridharan, *A Maritime History of India* (Publications Division, Government of India, 1965), p. 10.

[3] Radhakumud Mookerji, *Indian Shipping* (Longmans, Green and Co., Bombay, 1912), pp. 55-56.

is the earliest reference 'in Indian books to ocean-going ships out of sight of land'.[4]

The *Arthaśāstra* (II. 28) bears testimony to shipbuilding activity during the Maurya period (*c.* 322-200 B.C.). The admiralty was given the pride of place in the defence of the realm. It was under the control of an officer designated as *nāvadhyakṣa* or the superintendent of ships. He was concerned with not only the navigation of the ocean but also inland river transport. That one of his functions was to collect port duties which were many and varied confirms the existence of intensive maritime activity. During this period vessels were made of a variety of materials—timber, bamboo, inflated leather bags, baskets covered by skin, and so on.

Accounts of some foreign visitors to India confirm that shipbuilding had reached a high degree of perfection around the fourth century B.C. Megasthenes speaks of shipbuilders of the Maurya period who received their wages and victuals from the king for whom alone they worked. According to him, the admiral of the fleet used to let out ships on hire for the transport of both passengers and merchandise.[5] Pliny (first century A.D.) observes that some of the ships of the Maurya age had weighed seventy-five tons. While describing Taprobane (Sri Lanka), Pliny states that the sea between that island and India is not always of equal depth; in some channels it is so deep that no anchors can find the bottom, while at other places there are many shallows of no more than six paces in depth. The ships were therefore constructed with prows at each end for turning about in channels of extreme narrowness.[6] The Greek historian Arrian mentions the construction of dockyards and the existence of a tribe called Xathroi who specialized in making oars and transport vessels.[7] The Xathrians (probably the Greek corruption of Kṣatriyas) had built for Alexander thirty-oared galleys and trading vessels to carry the Greek army down the Indus.[8] The *Periplus of the Erythrean Sea* (*c.* first century A.D.) by a Greek author mentions the vast extent of Indian navigation and speaks of Indian coasts being studded with harbours, from which merchant vessels sailed to Persia, Arabia, Africa, and Red Sea ports. Two types of ships, namely *sangara* and *colandia*, have been mentioned in this work. Of these, the former were coastal vessels and the latter bulky, strongly built sea-going ones which were used for trade with Malacca and perhaps with China too.[9] The *colandia* was possibly somewhat akin to the two-masted Javanese outrigger ships of Borobudur sculpture (*c.* eighth or ninth century A.D.).

[4] *Journal of the Royal Asiatic Society* (April 1899), p. 482; see also Mookerji, *op. cit.*, p. 103n.
[5] Mookerji, *op. cit.*, pp. 102-3.
[6] *Ibid.*, p. 103.
[7] *Ibid.*, p. 102.
[8] R. C. Majumdar, *The Classical Accounts of India* (Calcutta, 1960), p. 75.
[9] Wilfred H. Schoff, *The Periplus of the Erythrean Sea* (Calcutta, 1912), pp. 46 and 243.

Inscriptions speak of Emperor Aśoka (*c.* 269-232 B.C.) sending abroad missionaries from India to propagate Buddhism. His son Mahendra and daughter Saṅghamitrā are said to have made a voyage from Tāmralipti to Sri Lanka for this purpose. In the days of Aśoka, India was brought into systematic contact with distant Greek kingdoms. V. A. Smith is of the view that Aśoka possibly maintained a sea-going fleet. He says: 'When we remember Aśoka's relations with Ceylon and even more distant powers, we may credit him with a sea-going fleet as well as an army.'[10]

According to the famous Pali chronicle, the *Mahāvaṁsa* (*c.* fifth century A.D.), Vijayasiṁha of Bengal with seven hundred men conquered Sri Lanka which was named Siṁhala after the name of his dynasty. The work also refers to an Indian ship of a large size. It is stated that the bride of Vijayasiṁha was brought to Siṁhala in a ship which could accommodate about eight hundred people. Kc mos Indicopleustes (*c.* A.D. 535), an Alexandrian monk, mentions Sri Lanka as a great resort of ships from all parts of India.[11] The *Samudda-vāṇija-jātaka* narrates the story of one thousand carpenters of a village who, having failed to furnish in time a delivery of goods for which they had been paid in advance, secretly built a ship and set sail for an island overseas.[12]

Fine ancient paintings of ships in the cave temples at Ajantā bear evidence of the shipbuilding activities in India during the period from the second century B.C. to the seventh or eighth century A.D. One of the paintings shows a sea-going vessel with high stem and stern, and three oblong sails attached to as many upright masts. Each mast is surmounted by a truck and carries a lug-sail. The jib is well filled with wind. A bowsprit projects from a structure on the deck, resembling gallows. The outflying jib is square in form like that borne till recent times by European vessels. The ship is provided with a deck and ports; steering-oars hang in sockets or rowlocks on the quarter; and eyes are painted on the bows. There is an additional oar behind. Two small platforms project fore and aft, and there are a number of jars under the canvas roof.[13] The vessel is of the *agramandira* type as defined in the *Yuktikalpataru*.

In striking contrast to the stray references mentioned above, the *Yuktikalpataru*, attributed to King Bhoja (*c.* eleventh century A.D.), offers an elaborate and analytical study of shipbuilding in ancient India.[14] The text mentions four classes of wood. The wood that is light and soft and can be easily joined belongs to the *brāhmaṇa* class; the wood that is light but hard and can be

[10] V. A. Smith, *Edicts of Aśoka*, Introduction, p. viii.

[11] J. Hornell, 'The Origin and Ethnological Significance of Indian Boat Designs', *Memoirs of the Asiatic Society of Bengal*, Vol. VII, No. 3 (1920), p. 212.

[12] *Jātaka Stories*, ed. E. B. Cowell, Vols. III-IV, Book 12, No. 466 (Pali Text Society, London, 1957).

[13] Mookerji, *op. cit.*, p. 41.

[14] *Yuktikalpataru*, ed. Pandit Isvara Chandra Sastri (Calcutta, 1917), pp. 223-29.

joined only with difficulty is of the *kṣatriya* class; the wood that is heavy but soft belongs to the *vaiśya* class; and the wood that is hard and heavy is of the *śūdra* class. Ships built with the *kṣatriya* class of wood are conducive to prosperity and happiness. The building of ships using different classes of wood is discouraged. Ships made of more than one class of wood are believed to promote neither happiness nor prosperity and are, moreover, liable to become dismembered or to rot soon after being launched. The *Yuktikalpataru* cautions that iron should not be used for joining the bottom planks of a ship lest the proximity of unsuspected magnetic iron rocks in the sea should cause damage to the vessel. Obviously the ships were meant to be used in sea voyages.

The ships are grouped into two major categories: *sāmānya* (ordinary) and *viśeṣa* (special). The *sāmānya* category of ships, meant for inland river traffic, has ten varieties depending on their dimension and capacity. These are: *kṣudrā* (24′×6′×6′), *madhyamā* (36′×18′×12′), *bhīmā* (60′×30′×30′), *capalā* (72′×36′×36′), *paṭalā* (96′×48′×48′), *bhayā* (108′×54′×54′), *dīrghā* (132′×66′×66′), *patrapuṭā* (144′×72′×72′), *garbharā* (168′×84′×84′), and *mantharā* (180′×90′×90′). According to the *Yuktikalpataru*, ships called *bhīmā*, *bhayā*, and *garbharā* are unsafe for navigation as their dimensions are such that they are not likely to keep steady and well balanced on the water. In the construction of *viśeṣa* ships, which are sea-going vessels, foils of iron and copper or loadstone are used. These are divided into two groups, *dīrghā* and *unnatā*, length being the predominant feature of the first and height that of the second. Depending on their length, breadth, and height ships belonging to the *dīrghā* class are of ten types. These are *dīrghikā* (48′×6′×4·8′), *taraṇī* (72′×9′×7·2′), *lolā* (96′×12′×9·6′), *gatvarā* (120′×15′×12′), *gāminī* (144′×18′×14·1′), *tarī* (168′×21′×16·8′), *jaṅghālā* (192′×24′×19·2′), *plāvinī* (216′×27′×21·6′), *dhāriṇī* (240′×30′×24′), and *veginī* (264′×33′×26·4). Of these, the first two kinds are deemed to bring good luck, the others ill luck. The *unnatā* type of ships, according to the *Yuktikalpataru*, comprises five varieties, namely, *ūrdhvā* (48′×24′×24′), *anūrdhvā* (72′×36′×36′), *svarṇamukhī* (96′×48′×48′), *garbhiṇī* (120′×60′×60′), and *mantharā* (144′×72′×72′).[15] Of these, *anūrdhvā*, *garbhiṇī*, and *mantharā* bring misfortune, while the other two are conducive to prosperity.

Indian shipbuilders took particular care in decorating the vessels. Sheets of gold, silver, copper, and their alloys were used for this purpose. Recommending different colours for four kinds of ships, the *Yuktikalpataru* says that a ship with four masts should be painted white, that with three red, that with two yellow, while the colour for a single-masted one should be blue. Carving of the faces of animals and birds on the prows of ships seems to have been in

[15]The figures indicated within brackets are based on measurements given by Mookerji, *op. cit.*, pp. 22-24. The cubits, however, have been converted into feet (1 cubit = 1·5 feet).

practice. On the body of the ships, however, figures of celestial beings as well as animals and birds used to be painted, as a few passages of the work suggest. Depending upon the size of the cabin, ships were of three classes. The type of vessel with a cabin running from one end of the ship to the other was termed *sarvamandira*. Such ships were designed to carry royal treasures, horses, and women. The second type, *madhyamandira*, had a cabin in the middle and was suitable in the rainy season and for pleasure trips by kings. The other type with a cabin towards the prow was called *agramandira* and deemed to be convenient for long voyages and naval warfare. Another work ascribed to Bhoja, the *Samarāṅgaṇa-sūtradhāra*, contains a description of various mechanical contrivances (*yantra*), one of which is termed *jalayantra*. The word suggests some machine associated with the operation of sea or river craft.

MEDIEVAL PERIOD

Accounts of foreign travellers constitute the main source of information on shipbuilding in India during the medieval period. Marco Polo (A.D. 1254-1324), who visited India towards the close of the thirteenth century, records interesting details of contemporary shipbuilding. The ships, he points out, were built with fir timber and were double-planked. They were caulked with oakum both within and without and were fastened with iron nails. The bottoms were coated with a preparation of quicklime and hemp pounded together and mixed with an oily substance procured from a local tree. There were large-sized vessels requiring a crew of 300, as well as smaller ships with 150 to 200 men. These ships were propelled by oars, each oar being worked by four men. The larger vessels had usually a single deck, and the space below the deck was divided into sixty small cabins or so depending upon the size of the vessel. An indication of the tonnage of a large-sized ship can be had from the fact that it could carry five to six thousand baskets of pepper. Usually such a ship had a strong helm, four masts, and as many sails. There were thirteen bulk heads in the vessel in order to guard against accidents. The process in the case of repairing a ship was to give a course of sheathing over the original boarding, forming a third course. If further repairs were required, the same process was repeated even to the number of six layers, after which the ship was rejected as useless.

Niccolo dei Conti (*c.* A.D. 1395-1469), an Italian traveller, records that India built some ships 'larger than ours'. Such ships used to have five sails each and as many masts, and were capable of containing 2,000 butts. Some of these ships were approximately 60,000 cubic feet in capacity. Their bottom was constructed with three layers of planks to enable them to resist the onslaughts of cyclonic weather to which they were exposed during monsoons.

Some ships were built in compartments in such a manner that should one part be shattered the other might accomplish the voyage.[16]

Another Italian traveller, Lodovico de Varthema (*c.* A.D. 1470-1510), describes Calicut as a flourishing centre of shipbuilding. In building ships, he says, the craftsmen of Calicut would not put any oakum between one plank and another, and yet they joined the planks so skilfully that water did not pass through them. Layers of pitch outside and an immense quantity of iron nails strengthened the structure. Two sails made of cotton were fixed to the ship. Anchors of the ship were made of marble.[17]

The *Āīn-i-Akbarī* of Abū'l-Fazl speaks of the maintenance of a naval department during the reign of Akbar (1556-1605). Large ships suitable for sea voyages were constructed at Allahabad and Lahore and along the west, east, and south coasts of India. The harbours were kept in excellent condition. Seamen were chosen for appointment on the basis of their knowledge of the tides, ocean depths, and wind directions. Sea-going war vessels of superior quality were built in Bengal, Masulipatnam, Sind, and Kashmir. Akbar had many craftsmen brought from countries abroad to construct the war vessels.[18]

The expansion of the Mogul empire called for a powerful navy to tackle the problem of protecting the coastal areas from depradations by pirates. Shipbuilding, therefore, received the attention of successive Mogul emperors after Akbar. Shaista Khan, who became the Governor of Bengal in 1664 during the reign of Aurangzeb (1658-1707), took measures to strengthen his naval force to quell piracy by the Arakanese and the Portuguese. Hooghly, Baleswar, Murang, Chilmari, Jessore, and Karibari were the main centres of shipbuilding during the period of his rule in Bengal.

Thomas Bowrey, an English traveller to India between 1669 and 1679, has left an account of the various types of ships and boats built in India during that period. Among these were *massoola* boats used for loading and unloading ships; *catamaran*, a type of boat with a capacity of three to four tons; and *patelas* capable of carrying a load of about 134 to 200 tons.[19] According to Fryer, who visited India around 1672-74, Aurangzeb maintained at Surat on the western coast four large ships for carrying pilgrims to Mecca. These vessels were 'huge unshapen things'. He also noticed three or four men-of-war and some ships carrying thirty or forty pieces of cannon.[20] Khafi Khan, a contemporary historian, speaks of a large ship, 'Gunj Suwaie', stationed at Surat which carried eight guns and 400 matchlocks. Shipbuilding was also patron-

[16]R. H. Major, *India in the Fifteenth Century*, II (Hakluyt Society, London, 1857), pp. 10, 21, and 27.

[17]*Travels of Varthema*, ed. G. P. Badger (Hakluyt Society, London), pp. 152ff.

[18]*Āīn-i-Akbarī*, Vol. I, trans. H. Blockmann (Calcutta, 1873), pp. 279-82.

[19]Mookerji, *op. cit.*, pp. 234-35.

[20]*Ibid.*, p. 237.

ized by Maratha rulers. Śivājī (1630-80), who executed a programme of fitting out a Maratha fleet between 1659 and 1664, had about 500 ships constructed. He had at Vijayadurga, Kolaba, Sindhuvarga, Ratnagiri, and Anjanavela five well-equipped docks capable of turning out men-of-war. In 1698 the command of the Maratha navy passed on to Kanojee Angira who had to his credit a series of victories in naval engagements with the rising foreign powers. The Maratha maritime tradition was thus continued through the seventeenth century.

The foregoing is a brief account of shipbuilding in India from the earliest times up to the end of the seventeenth century. The evolution of shipbuilding through this period has been, as Sridharan says, 'one of progress from rafts and river-craft to multi-oared galleys, culminating in large seagoing, sailing vessels. The materials and wherewithal for ship construction were obtained from purely indigenous sources; artisans were, in the main, Indians, though some foreign technicians. . .were pressed into service from time to time.'[21] By the time the British came, the technique of shipbuilding had reached a fairly high standard of perfection in the country. Things changed with the consolidation of British power in India which saw a gradual introduction of western techniques in this industry. As the industry became more and more modernized in keeping with the progress of science and technology, earlier indigenous methods of shipbuilding were abandoned in the course of time except in respect of local riverine transport.

[21]Sridharan, *op. cit.*, p. 126.

15

ENGINEERING AND ARCHITECTURE IN ANCIENT AND MEDIEVAL INDIA

THE achievements of Indian people in the field of engineering began in the proto-historic times, from the third millennium B.C. or even earlier. The ancient Indian civilization like those of Iran, Iraq, Mesopotamia, and Egypt showed skill in the construction of buildings and granaries, in town-planning, and in the provision of civic amenities like community baths and other sanitary conveniences.

The earliest evidence of the technical skill of the ancient Indian lies perhaps in the numerous tools he carved out of stone in the course of his struggle for existence. A long period of trial and error requiring power of observation and the application of what was observed in his natural surroundings must have intervened between this period of the fashioning of crude pebble tools and the development of the hand-axe. The early palaeolithic age was followed by the middle palaeolithic age when he made tools on fine-grained flakes, which were smaller in size and included scrapers, points, awls or borers, blades, etc. These tools, archaeologists think, might have been used for dressing animal skins and barks of trees, smoothing the shafts of spears, cutting, chopping, etc. They may be classified into two groups—core and flake—according to the way in which they were made. Core tools were made by chipping or flaking away a stone until the desired shape was obtained. Flake tools were made, however, by detaching a large piece from a stone and then working it into the requisite shape. A third classification put forward by some archaeologists is the chopper-chopping tool group; these tools were made from pebbles by knocking off a portion to make the cutting edge. The new stone age (*c.* 400 B.C.) saw the growth of what is called the small stone microlithic industries of India. At Langhnaj in Gujarat have been discovered pottery and tools as well as sandstone slabs, flattened on one side and used for grinding. The next stage in the growth of man's skill in India is termed the neolithic revolution when he started settling down, making tools from bones of animals he hunted. Excavations at Burzahom near Srinagar have revealed that the earliest inhabitants 'of this valley lived in circular or oval pits dug into the *Karewa* soil. Evidence of post-holes along the edge of the pits indicated a timber superstructure covered over by a thatched roof. The pit-dwellers provided landing steps to reach down the floor of their house, where stone hearth and small-sized storage pits were met with. In the succeeding period, red ochre was found used as a colour-

ing material for the floor'.[1] Such pit-dwellings have also been found at Nāgārjunakoṇḍa in the Krishna valley.

CIVIL WORKS OF INDUS VALLEY PERIOD

Remains of the Indus valley civilization (fourth-third millennium B.C.) unearthed at Mohenjo-daro and Harappa now in Pakistan, Lothal in Gujarat, and Kalibangan in Rajasthan amply testify to the well-developed technical skill of ancient Indians. Mohenjo-daro in Sind and Harappa in the Punjab are deemed to have been the capital cities of the Indus valley. Each of the towns was approximately three miles in circuit. The dwellers of Mohenjo-daro were among the world's pioneers in city construction. The largest buildings unearthed in Mohenjo-daro measure 73·76m.×34·13m. Road alignments were from east to west and from north to south, each crossing the other almost at right angles in a chessboard pattern. The width of the roads varied from 10·05 m. to 5·48 m., depending on the requirements of traffic. There is evidence of attempts to pave the roads at some places.

The houses unearthed are commodious and well built, indicating the civil engineering skill of the people. The bricks were well burnt and of various proportions, namely, 27·94 cm.×13·33 cm. or 13·97 cm.×5·71 to 6·98 cm. The bricks were cast in open moulds by the open stack method with wood fuel to burn them. Although the Indus valley people acquired considerable mastery over brick-making they have left us no evidence of decorative brick work. Most of the houses had more than one floor, although the number of rooms on the first floor was presumably limited. Nevertheless, the technique of load distribution must have been mastered by them. The houses were closely built. The average middle class dwelling was about 9·14 m.×8·22 m., consisting of four or five living rooms. These houses were constructed with due provision for sanitary amenities. A typical house included a central courtyard; a well-room; a paved bath; a sewer pipe protected by brick work which ran beneath the floor into the public drain in the street, providing drainage from the courtyard; and a pipe running vertically in a wall to carry sewage from the upper floor. The use of a pulley wheel for drawing water from the wells was known as may be inferred from certain depictions in terracotta.

Among the ancient remains found in the Indus valley are two remarkable structures, viz. the Great Bath situated in the citadel mound at Mohenjo-daro and the Great Granary at Harappa. The overall dimension of the Great Bath is 54·86 m.×32·91 m., while the swimming pool, situated in the centre of a quadrangle with verandahs on all sides, measures 11·88 m.× 7·01 m. The massive outer walls of the building are 2·13 m. to 2·43 m. thick

[1] M. N. Deshpande, 'Archaeological Sources for the Reconstruction of the History of Sciences of India', *Indian Journal of History of Science* (May 1971), p. 5.

at the base with a batter on the outside. There are at either end of the swimming pool a raised platform and a flight of steps with another platform at the base of each flight of steps. The pool is lined with finely dressed brick laid in gypsum mortar with an inch of damp-proof course of bitumen. From an analysis of samples of bitumen at Mohenjo-daro, Forbes has determined that the cement contained in it was a kind of refined rock asphalt.[2] The Great Granary at Harappa consists of a series of parallel walls, each 15·9 m. long standing in two sections divided by a passage 7·01 m. broad. The building thus comprises two similar blocks, together measuring 51·51 m. × 41·14 m. The walls are about 2·74 m. thick. In each block there are six halls alternating regularly with five corridors. Each of the halls is partitioned into four narrow divisions by three equidistant, full-length walls terminating in broader piers at the ends. The piers are made of burnt brick, while the partition walls are of mixed construction.

The remains of Lothal, nearly 3·2 km. in circumference, remind one of Mohenjo-daro in miniature. The town was more or less designed after the patterns of Mohenjo-daro and Harappa with streets constructed at right angles. An important feature was a thick mud wall, reinforced with burnt bricks on its northern periphery, which served as a defence against floods. The blocks of the town were raised on mud bricks to further provide a degree of security against floods. There is evidence of civic amenities like brick-built wells, underground sewers, cesspools, and brick-paved baths. Among the important structures are a dock with a wharf and a warehouse. The dock is a testimony to the engineering skill of its builders and was, according to Rao, 'the first ever venture made by man to build an artificial basin for sluicing ships at high tide'.[3] In its conception and engineering it surpasses the Roman and Phoenician docks of later times.[4] Its embankment walls measure 212·4 m. on the west, 36·4 m. on the north, 209·3 m. on the east, and 34·7 m. on the south. The basin and walls are lined with burnt bricks. It was built off the main stream in order to reduce the likelihood of silting and flooding, and incorporated a water-locking device and a spillway to ensure floatation of ships during low tide. Ships would enter the dock at high tide. The inner walls were made perfectly vertical so that cargo could be loaded and unloaded directly between the ships and the wharf. The wharf, measuring 260 m. ran along the western wall of the dock. From the wharf goods could be taken to the warehouse adjacent to it. The warehouse had a floor area of 1,930 sq. m., larger than the granaries of Mohenjo-daro and Harappa. The structure stood on a 4-metre high platform on which were raised sixty-four blocks of mud bricks,

[2] R. J. Forbes, *Bitumen and Petroleum in Antiquity* (Leiden, 1936), pp. 29, 38, 42, and 58.
[3] S. R. Rao, *Lothal and the Indus Civilization* (Asia Publishing House, Bombay, 1973), p. 56.
[4] *Ibid*, p. 70.

each block 3·6 m. square and 1 m. high. The blocks were interspersed with 1-metre wide passages to allow ventilation and easy access to the goods. On top of the blocks a superstructure of timber was raised.

Archaeologists have found in Kalibangan ruins of a town and a fortified citadel on an artificial platform of mud and mud-bricks six to seven metres high. Though smaller than Mohenjo-daro, Harappa, and Lothal, Kalibangan was a well-planned town with houses built in oblong blocks flanking the arterial streets, running in cardinal directions. Lack of street drains suggests that the sanitation of Kalibangan was not as rigorously maintained as in the other Harappa towns and cities. There were, however, private baths, soakage jars, and drains. Excavations reveal evidence of the use of copper axes, which 'clearly shows the beginning of metallurgy as early as 2450 B.C.'[5]

The Indus valley people thus achieved considerable proficiency in engineering and technical skill, as shown by their use of building materials and their construction of roads, drains, etc. A system of weights and measures was in vogue. Weights found at Mohenjo-daro and Lothal are normally of cut and polished cubes of chert. Finds of graduated scales made of shell at Mohenjo-daro, of bronze rod at Harappa, and of ivory at Lothal indicate their knowledge of practical geometry and land surveying. The average distance between the successive divisions of the scales is 6·70 mm., 9·34 mm., and 1·70 mm. respectively. Terracotta plumb-bobs and an instrument made of shell for measuring angles of 45°, 90°, and 180° were also found at Lothal.

VEDIC PERIOD

Whereas the Indus valley civilization was essentially urban, relying on extensive trade and depending upon organized city life for its existence, the Vedic civilization was primarily pastoral or an agricultural one in which complex urban organization was unknown. It is not surprising, therefore, that highly developed cities like Harappa and Mohenjo-daro did not appear during the Vedic period and that technology was in evidence only to the extent of providing for the necessities of village life.

Vedic texts are replete with words descriptive of dwellings and contrivances which provide an idea of the extent of technological knowledge of the period. The word *pura* occurs frequently in the *Ṛg-Veda* (I. 53.7, 58.8; III. 15.4; etc.) and later Vedic texts and appears to mean a fort or fortification. Hundred-walled forts are also mentioned (I. 166.8; VII. 15.14). The term *mahā-pura* (great fortress) appears in the *Taittirīya Saṁhitā* (VI. 2.3.1), *Aitareya Brāhmaṇa* (I. 23.2), and other texts. The type of material with which the forts were constructed is not clearly indicated. In all probability they were temporary structures, perhaps merely ramparts of earth with ditches and stone

[5] Deshpande, *op. cit.*, p. 6.

walls, or possibly made of wood. In one place (IV. 30.20) the *Ṛg-Veda* refers to a fort made of stone (*aśmamayī*), but Macdonell and Keith think this may mean sun-dried bricks.[6]

Gṛha or *dama* is used to denote a house. The sides of the house were called *pakṣa* and the door *dvāra*, while the door with its framework was termed *ātā*. Macdonell and Keith, following Zimmer, believe that houses were constructed with wood.[7] From passages in the *Atharva-Veda* (III. 12; IX. 3), Zimmer has suggested the following possible method of construction. On a good site, four pillars (*upamit*) were set up, against which beams were propped as supports (*pratimit*). The pillars were then joined on top by cross beams (*parimit*). Bamboo (*vaṁśa*) was used as ribbing over a ridge called *viṣūvant*. Finally, the ribs were covered with a kind of thatching. The walls were set up with grass tied in bundles (*palada*) which were bound together.[8] Some terms like *sadas* (sitting room) and *patnīnāṁ sadana* (wives' room)[9] suggest that the dwellings were compartmented.

References to private dwellings in Gṛhyasūtra texts indicate that spacious houses in the later Vedic period were quite common. Such a house appeared to contain among other things an assembly room and a resting or retiring room, with a latrine detached from the main building. An arrangement of water supply was evidently part of house construction. Ponds, wells, and other reservoirs of water are also mentioned in Gṛhyasūtra texts. Some of these were presumably public works meant for general use. There are references to bridges, roads, cross-ways, and squares.

The chariot (*ratha*) was an important piece of military equipment from the beginning of the Vedic age. It generally had two wheels (*cakra*), each consisting of rim (*nemi*), felly (*pradhi*), nave (*nabhya*), and spokes (*ara*), connected by a non-revolving axle (*akṣa*), the end of which (*āṇi*) fit into the nave holes (*kha*). Solid wheels were also sometimes used. The body of the chariot (*kośa*) was attached to the axle and was possibly constructed with wicker work or leather stretched over a light wooden frame. A seat for the warrior was provided. From the axle a pole (*īṣā*) ran perpendicular to the front of the chariot where it was joined to a yoke (*yuga*) which was secured to the necks of the horses, usually numbering two although three or four were common, and sometimes even five. The horses were also tied at the shoulders by means of traces. Reins were attached to bits in the horses' mouths. The chariot consisted also of other minor auxilliary parts. The *Śulvasūtra* of Āpastamba (VI. 5) gives the following dimensions of the chariot: axle, 104 *aṅgulis* (finger-breadths);

[6]A. A. Macdonell and A. B. Keith, *Vedic Index of Names and Subjects*, Vol. I (London, 1912), p. 538.

[7]*Ibid.*, p. 230.

[8]H. Zimmer, *Altindisches Leben*, p. 153.

[9]Macdonell and Keith, *op. cit.*, Vol. I, p. 231.

pole, 188 *aṅgulis*; and yoke, 86 *aṅgulis*. The driver of the chariot (*sārathi*) stood on the right while the warrior (*savyaṣṭhā*) was positioned on the left, either standing or sitting.

Mention of such words as *kulyā* (canal) and *khanitrimā āpaḥ* (water obtained by digging) in the *Ṛg-Veda* (III. 45.3 and VII. 49.2 respectively) suggests that some kind of irrigation system which utilized well water was in existence. Water used to be raised by a wheel to which a strap with a pail attached to it was fastened.

POST-VEDIC PERIOD

For evidence of the engineering and technical skills of ancient Indians in the early post-Vedic period we have to depend largely on literary sources. We are told of high walls with watch towers, strong ramparts with buttresses, and gates. A number of towns and cities, called *janapadas*, of considerable importance had developed before the seventh century B.C. Noteworthy among them were Ayodhyā, Vārāṇasī, Campā, Kāmpilya, Kauśāmbī, Mathurā, Mithilā, Rājagṛha, Roruka, Sagala, Sāketa, Śrāvastī, Ujjayinī, and Vaiśālī.[10] An example of a stone wall around a hill fortress before the sixth century B.C. has been unearthed at Girivraja near Rājagṛha—modern Rajgir. But books referring to this earlier period make no mention of stone except for pillars or staircases. Only while describing a fairyland is a palace of stone referred to. The presumption, therefore, is that the superstructures of buildings during this period were all made of wood or brick. Reference may in this connection be made to the ruins of some other ancient cities like Takṣaśilā and Sāñcī. Takṣaśilā is mentioned as a flourishing city and centre of learning in Buddhist literature probably compiled at least in the fourth century B.C. Archaeological excavations at the Bhir Mound have revealed several layers, of which the latest and uppermost was quite clearly of the late third or early second century B.C. There does not appear to exist any direct evidence for dating the lowest layers of the ruins. At any rate, the ruins unearthed in the Bhir Mound bear adequate testimony to the kind of house-building technique in vogue at the time. The buildings 'were of rubble masonry, in which kanjur and limestone, finished with a coating of mud-plaster, were used'.[11] The remains of a fairly large house, with a courtyard and pillared hall and flanked by narrow, blind alleys have also been excavated in the western part of the Bhir Mound.

City life became more and more organized and by the time of Candragupta Maurya (*c.* 324-300 B.C.) it had taken a clear shape. There is evidence of the use of wooden piles in preparing the foundations of houses in soft soil

[10] T. W. Rhys-Davids, *Buddhist India* (Calcutta, 1959), pp. 17-21, 33.

[11] *Buddhist Remains in India*, ed. A. C. Sen (Indian Council for Cultural Relations, New Delhi, 1956), p. 67.

during the pre-Maurya period.[12] And wood continued to be an important constituent of house-building during the days of Candragupta. The testimony of contemporary Greek historians shows that a wooden palisade was erected at this time for the fortification of Magadha's capital Pāṭaliputra against floods.[13] Other types of fortification were also known.[14]

Kauṭilya's *Arthaśāstra* affords a glimpse of Indian approach to town planning about this time. Kauṭilya's view of an ideal city is more or less in harmony with the description of Pāṭaliputra given by Megasthenes and other Greek writers. The *Arthaśāstra* devotes one of its chapters (II. 3) to fortifications. Elaborate discussion follows in the next chapter about the construction of royal buildings and houses for different categories of citizens. Roads of various dimensions are prescribed for different purposes. According to Kauṭilya, the *durga* or fortified city is one of the seven constituent elements of the state. The meticulous way in which he deals with the lay-out and organization of forts gives the impression that the science of fortified city-building had already advanced considerably.

The celebrated Chinese pilgrim Fa Hien who visited Magadha during the reign of Candragupta II (*c.* A.D. 380-413) was struck with wonder at the sight of the royal palace of Aśoka (*c.* 269-232 B.C.) as also the houses set up by him for dispensing charity and medicine. Fa Hien is on record as having noted that the palace of Aśoka was not a work of men, but of 'spirits which piled up the stones, reared the walls and gates, and executed the elegant carving and inlaid sculpture-work in a way which no human hand of this world could accomplish'.[15] Mention may be made in this connection of the ruins of a hundred-pillared hall discovered by excavations around the site of Mauryan edifices. One of the important innovations of Aśoka was the substitution of stone for wood and brick. Structures and monuments of various types were set up in the country during his reign. The Mauryas introduced rock-cut architecture and the practice of highly polishing the surface of sandstone pillars. The high polish, besides lending splendour, also rendered the surface water-repellant and resistant to actions of weather.

BUDDHIST *STŪPAS* AND *VIHĀRAS*

In the construction of religious edifices like *stūpas* and *caitya-gṛhas* the Buddhists showed their engineering skill. Construction of *stūpas* and *caityas* was

[12] *Indian Archaeology*, 1962-63—*A Review*, ed. A. Ghosh (Archaeological Survey of India, New Delhi), p. 47.

[13] *Ancient India as Described by Megasthenes and Arrian*, trans. J. W. McCrindle (Calcutta, 1926), pp. 65-66.

[14] *Kautilya's Arthasastra*, trans. R. Shamasastry (Mysore, 1961), p. 50.

[15] *The History and Culture of the Indian People: The Age of Imperial Unity* (Bharatiya Vidya Bhavan, Bombay, 1968), p. 86.

an important aspect of Buddhist religious life. The word *stūpa* is derived from the root *stūp*, meaning 'to heap', and suggests the mound shape and method of construction of these edifices, while the word *caitya* is derived from *citi* (altar).[16] *Stūpas* are pre-Buddhist in origin, being associated with burial mounds. The earliest Buddhist *stūpas* were most probably low mounds consisting of layers of piled-up earthen tumulus which were separated from each other by thinner layers of stone chips and cloddy clay. The proportions of *stūpas* after construction were enlarged in some cases, and a *stūpa* is sometimes seen to have been enlarged several times. For this reason, and because of wreckage and decay, it is not always possible to determine the exact shape and type of construction of the original *stūpa*. The earliest ones were built solid without any interior structural support or fill. Of the earliest dated *stūpas*, those erected by Aśoka were made of bricks and mud mortar. The Śuṅga period saw some innovations in construction like providing a veneer of hammer-dressed stones and in plastering the surface of the dome. Gradually the advantage of filling the core with rubble or other material was recognized. And the outward thrust of the fill material on the facing wall was minimized by dividing the inner space into compartments in the form of boxes or radiating spokes like those of the wheel of a cart. The stone railings and gates of *stūpas* at Barhut and Sāñcī clearly point to the earlier prototypes being made of wood.

The growth of Buddhism also inspired the establishment of monasteries (*vihāras*). The earliest monasteries were probably simple dwellings made of wood, rubble and mud, or other perishable materials. Thus the *vihāra* had a humble beginning with a building having a series of cell-like rooms, set around facing an open space. The early Buddhist cave monasteries were quadrangular in shape, a typical example of which has been found at Nāsik. This comprises a hall about 4·2 metres square with two cells in each of the three sides. The basic pattern for such *vihāras* must have been evolved by the second century B.C. as seen from some of the specimens at Ajantā. The *vihāra* had later a covered *maṇḍapa* (courtyard) in the centre and with the installation of Buddha's image inside the cell in the back wall it became a *caitya*-cum-*vihāra*, serving the purpose of a shrine as well. At Nāgārjunakoṇḍa separate *caitya* halls were provided in the *vihāra* enclosures. The *vihāras* gradually became larger, some of them being double-storeyed.

The *stūpa* structure in its more developed form included a circular passage and a railing around it with gates (*toraṇa*) as seen at Sāñcī (Plate I). Those in the South did not have the *toraṇas* but often had projected platforms (*āyaka*) at the cardinal points on which rested a row of tall cylindrical monolith pillars as at Jaggayyapeta, Amarāvatī, etc. The railings of the Amarāvatī *stūpa* are made

[16] R. Sengupta, 'The Motif on the Facade of the Visvakarma Temple at Ellora', *Museums and Museology : New Horizons* (Agam Kala Prakashan, Delhi, 1980), pp. 223-24.

of marble and the dome also is covered with slabs of the same material. The *stūpa*, a solid hemispherical dome (*aṇḍa*), usually was placed on one or tiered bases and surmounted by a railed pavilion (*harmikā*). Later specimens show more ornate forms, the base-terraces as also the umbrellas being multiplied as at Nālandā (Bihar), Ratnagiri (Orissa), and other places. The outer surface of the basal cylinder (*medhi*) in southern examples, however, received encasing slabs sculptured tastefully as at Amarāvatī (Plate II), Nāgārjunakoṇḍa, etc.

Another type of Buddhist structure was the *caitya-gṛha*, a *stūpa*-cum-sanctuary. Initially, the *stūpa* was the object of worship. Later, an image of Buddha was either placed on it as at Ajantā and Ellorā (Plate III), or worshipped singly as at Nāgārjunakoṇḍa. The *caitya-gṛha* usually had an apsidal ground plan with the *stūpa* in the apsidal end and a central nave separated from the side aisles by a row of pillars. Unfortunately no structural *caitya-gṛha* survives, but the rock-cut examples depict them with gabled wooden roofs, initially simple in form, and with wooden pillars arranged with an inward rake to counter the outward thrust of the gabled roof. The latest examples at Ellorā show a logical development into a two-tiered roof with trusses.

The design of a rock-cut *caitya-gṛha* or *vihāra* was first planned by an architect or master craftsman. In choosing a suitable site he had to take into account such factors as the type of rock and whether it was free of faults, the existence of a suitable ledge from where the cave excavation could be started, and the proximity of spring or river water for drinking and bathing. The actual work must have been preceded by a detailed plan. It was necessary to know the exact position and size of stone blocks to be left standing which would later be carved into the desired shapes. For this precise measurements were necessary. Sketch-books containing patterns of the decorative stone carvings were no doubt essential. Some examples of unfinished caves show that the procedure was to excavate them from the ceiling downwards, thereby minimizing the need for scaffolding. As the rough cutting was being done inside the cave, simultaneously the decorative finish of the cave face would be in progress. This is borne out by some examples of caves which were abandoned before final excavation of the interior, although the face had been completed. Scaffolding was used for carving the capitals on the pillars.

Buddhist temples followed the contemporary architectural styles, as did the Jaina and Brāhmaṇical. There are a few very early Buddhist temples still standing from which one can get an idea of the type of construction employed in the superstructure. Wood was no doubt employed to a great extent. The earliest Buddhist temple standing, temple No. 17 at Sāñcī, is made of stone. Among the marvels of Buddhist architecture is the tower of the temple at Sārnāth which with its seven clearly marked receding storeys rose to a height of 33·4 m. The pyramidal structure is decorated by mounting

a miniature *stūpa* and *harmikā* pinnacle. Similarly imposing is the shrine at Bodh Gaya with its 55-metre temple spire. Superseding the architectural magnificence of both Sārnāth and Bodh Gaya stand the remains of Nālandā, one of the greatest seats of learning in ancient India. The lay-out of the campus with its 33·4-metre high *stūpa* and the colleges and dormitories must have called for elaborate architectural designing and engineering technique. There is evidence of the use of both brick and timber in construction.

TEMPLE ARCHITECTURE

The Gupta period (*c.* A.D. 300-600) saw the beginnings of systematic construction on the basis of structural principles in temple architecture. The basic elements are a square sanctum (*garbhagṛha*) for the image, a small pillared portico (*mukhamaṇḍapa*), and sometimes a covered circumambulatory passage (*pradakṣiṇapatha*) around the sanctum. The characteristic of the early temples is a flat roof as found at Sāñcī (Plate IV), Tigawa, and Eran (all in Madhya Pradesh); later temples such as are seen at Deogarh (Madhya Pradesh) and Bhitargaon (Uttar Pradesh) show a rudimentary spire (*śikhara*). There was a tendency during this period in stone construction to use stones larger than what the size of the building warranted. This was because the relationship between the strength and stability of construction and the economy of materials was yet to be understood. The stones were usually well cut and finely dressed, but no mortar was used. The stone was usually prepared at the site of the quarry. After the initial block of stone had been removed from the living rock, it was sectioned by making a groove along the desired division and then sinking holes into this groove at intervals. Wooden wedges were then pounded into these holes. On being wetted, the wood expanded, thus breaking the stone along the line of the groove. The blocks were faced first with a large iron chisel and then with a small one. Fragments of carvings found at some quarries suggest that the sculpturing of the stones was also usually done at the quarry site, although sometimes this was done after the stone had been set in its place on the temple itself. All of this entailed accurate measurements. Models to scale were perhaps sometimes employed.

From about the fifth century A.D. brick-built religious structures, both Buddhist and Brāhmaṇical, gradually became common in the alluvial plains. These include Buddhist *caitya* halls, monasteries, and *stūpas* as well as Brāhmaṇical temples. Bricks were easy to procure in the plains, whereas stone was not always readily available. And bricks also afforded the advantage of convenient handling and flexibility in construction technique because of their small size. One difficulty encountered in the use of bricks was the bridging of spaces as in the case of doorways, windows, and other openings. The craftsmen attempted to overcome this problem by using exceptionally

large bricks, some early examples being more than 50 cm. long. But even this was not always sufficient to surmount the difficulty, and so lintels of wood were resorted to. Stone lintels were subsequently found to be preferable to wooden ones. At one period brick structures with stone dressings became a rather common type of construction. Another method of spanning a gap was to oversail the courses of brick until they met. The vaulted roofs of *caityas* were constructed in this manner, a thick coating of plaster being applied over the surface to create the curvilinear shape of a vault. But the next logical step—to develop the arch in which the bricks act as supports to one another—did not take place until after the advent of the Muslims. There occur a few examples of experiments in this direction, the most notable being the entrance to the shrine at Bodh Gaya, although it is possible that this arch was constructed as part of a later restoration.

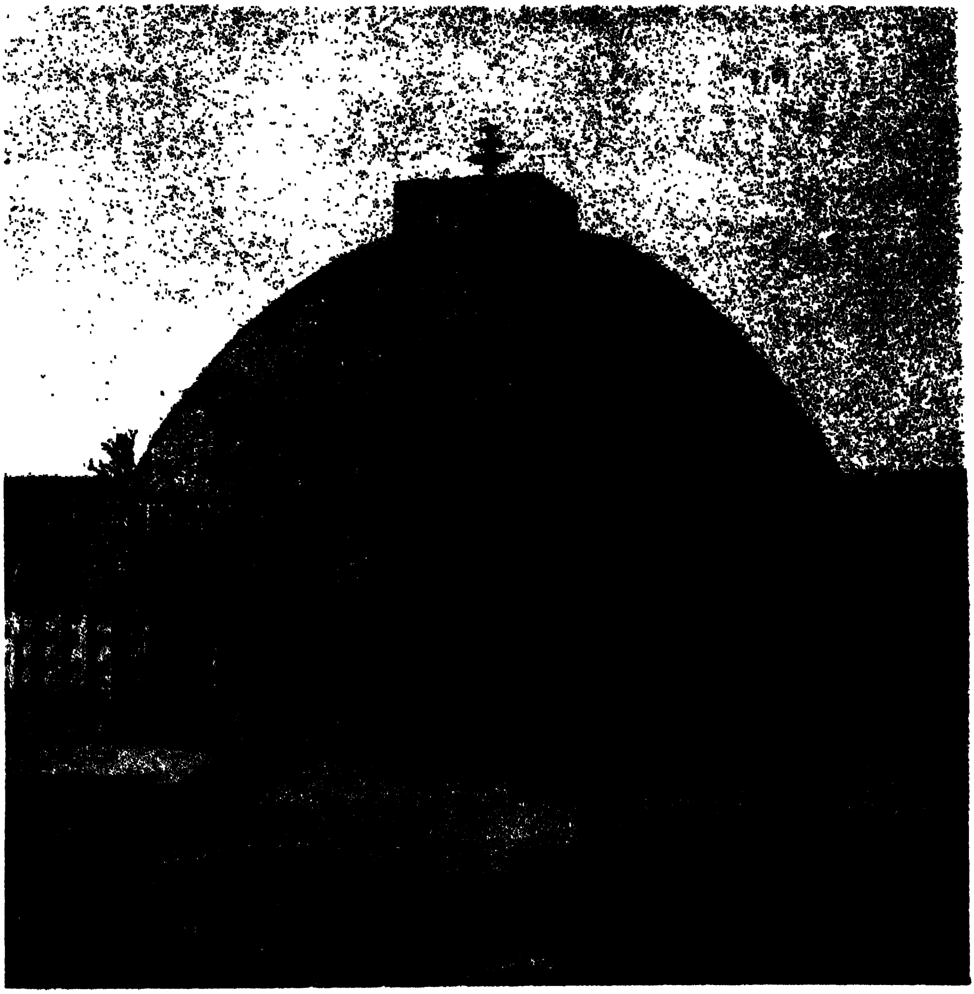
The post-Gupta period witnessed brisk building activity with experiments in various temple forms. Interesting results of such experimentations are seen at the principal centres at Aihole, Badami, Mahakuteswar, Pattadakal (all in Bijapur district), and Alampur (Mahbubnagar district). At Aihole the Lād-Khān Viṣṇu temple (sixth century), Meguti Jaina temple (seventh century), and Kontguḍi Śiva temple (seventh century) typify the *maṇḍapa* style with the shrine against the back wall of the pillared hall called *maṇḍapa*; its sloping roof in three tiers has a *śikhara* in the centre and is supported by pillars of receding heights. The Durgā temple (eighth century), though its roof is constructed on the same principle, has an apsidal plan in imitation of the Buddhist *caitya-gṛha*. Similar structures are also to be found at Chejarla (Guntur district) and Ter (Osmanabad district). Subsequent development is observed in the later examples in which components of the sanctum have a northern *śikhara*, a pillared hall carrying a flat roof, and a porch. This is exemplified by the Huccimalliguḍi temple and others, sometimes with a little adjustment of the *śikhara* in both plan and design. Such specimens are found at Alampur (eighth century), Pattadakal (eighth century), Osian (Jodhpur district, ninth century), Roda (Sabar Kanta district, ninth century) (Plate V), Jageswar (Almọra district, ninth-tenth century), etc. The South Indian temples of the *vimāna* (lit. well-proportioned) type with a pyramidal *śikhara* made their earliest appearance at Badami in the simple form of the temple known as Mālegiṭṭi-Śivālaya (garland maker's temple). Later variants and developed forms of *vimāna* with *śālās* (miniature oblong shrine with barrel-vault roof), *karṇa-kūṭas* (miniature square shrine at the corner of the roof), and *nāsikās* (arched opening above the superstructure wall, projecting from the facade) are seen on the Virupākṣa temple (eighth century) at Pattadakal, Shore temple (eighth century) at Mahabalipuram (Plate VI), Kailāsanātha temple (eighth century) at Kanchipuram, Bṛhadīśvara temple (tenth century) at

Tanjore, Airāvateśvara temple (twelfth century) at Darasuram, etc. Equally interesting are the Hoysala (twelfth-thirteenth century) temples at Halebid and Belur, famous for their intricately carved sculptured decorations, a kind of which is also seen in some of the Vijayanagara (fourteenth century) temples noted for large-sized *maṇḍapas*. Gateways (*gopuram*) to the temple enclosures constituted another important feature (Plate VII). These were usually capped by a vaulted roof, the later examples soaring high, the oblong size at each storey diminishing with the height. Although there are many examples, the temple-city at Srirangam has tall *gopurams* fixed in the seven concentric enclosure walls around the temple of Raṅganāthasvāmī (Viṣṇu) which is unique.

The vaulted roof was widely distributed and appeared on structural temples in North India from the eighth century. The Vaital-Deul (eighth century) at Bhuvaneswar, the Teli-kā-Mandir (ninth century) at Gwalior, and Nava-Durgā temple (ninth century) at Jageswar are examples of this type. Though essentially linear in elevation, the North Indian *śikharas* have some variations. While at Bhuvaneswar itself the typical Orissan form is represented by the Siddheśvara and Kedāreśvara temples (tenth century), the Rājārāṇī temple (eleventh century) shows an interesting experiment with miniature *śikharas* clustered around the *jaṅghā* (bottom portion of the spire) as in the temples of western and central India including those at Khajuraho. The Liṅgarāja temple (eleventh century) shows the culmination and grandeur of this type of temple (Plate VIII), but the Sūrya temple (thirteenth century) at Konarak (Puri district) in its original form with bold and lively sculptural decorations must have been a magnificent work. At Khajuraho, again, a beginning was made with a plain *śikhara* without any embellishment of the miniature spires (*urū-śṛṅgas*) which became the characteristics of the later examples. The temple components were *ardha-maṇḍapa* (entrance porch), *maṇḍapa* (hall), *antarāla* (vestibule), and *garbhagṛha* (sanctum), the entire structure being placed on a high platform and the walls decorated with beautiful carvings (Plate IX). The result of these experiments was the emergence of two broad temple architectural styles one predominating in the North called *nāgara* and the other common in the South called *drāviḍa* or *vimāna*.

The main structural component during the post-Gupta period continued to be stone. One wonders how the big slabs of stone used in the temple structures were transported and set up in position to make the temples. From reliefs carved on temples and from a manuscript describing the building operations of the temple at Konarak one gets an idea of the methods employed in transporting large stones to the construction site and hoisting them into place. They were transported on barges along rivers and streams or pulled by elephants over wooden rollers. They were lifted into place by means of

PLATE I



SANCI: STUPA

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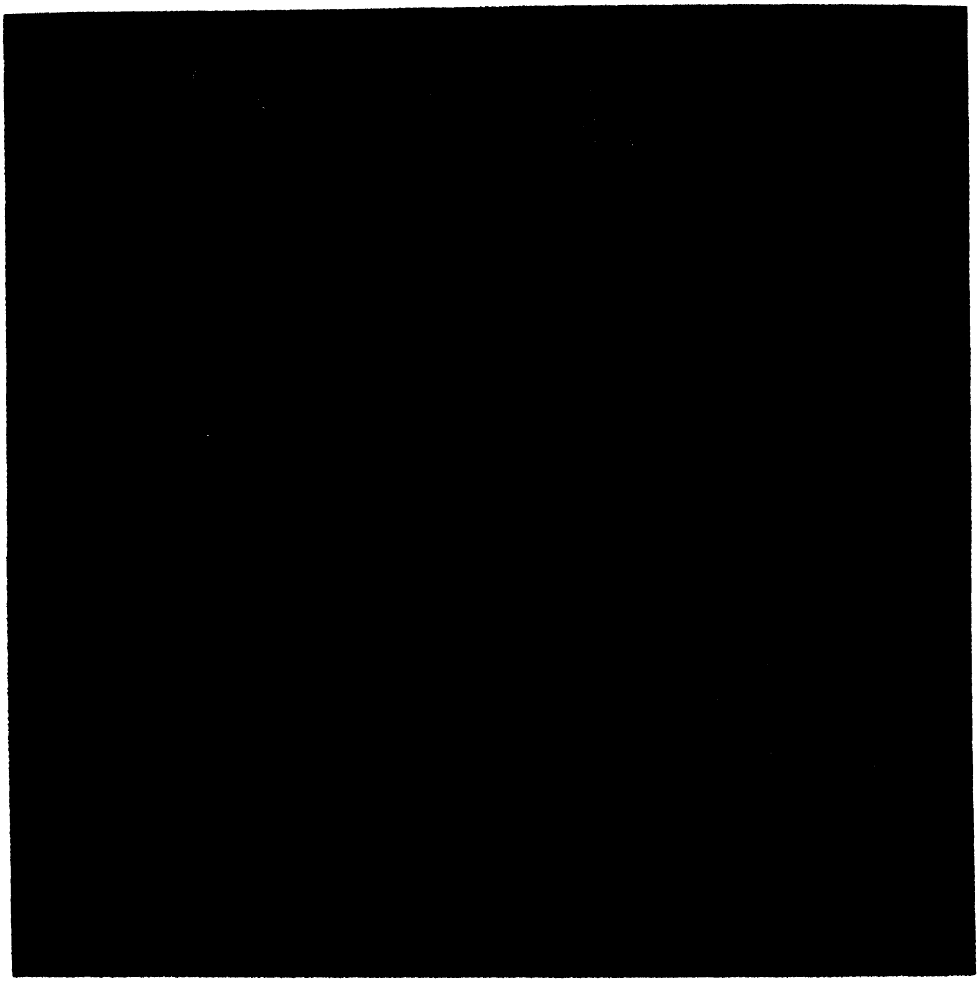
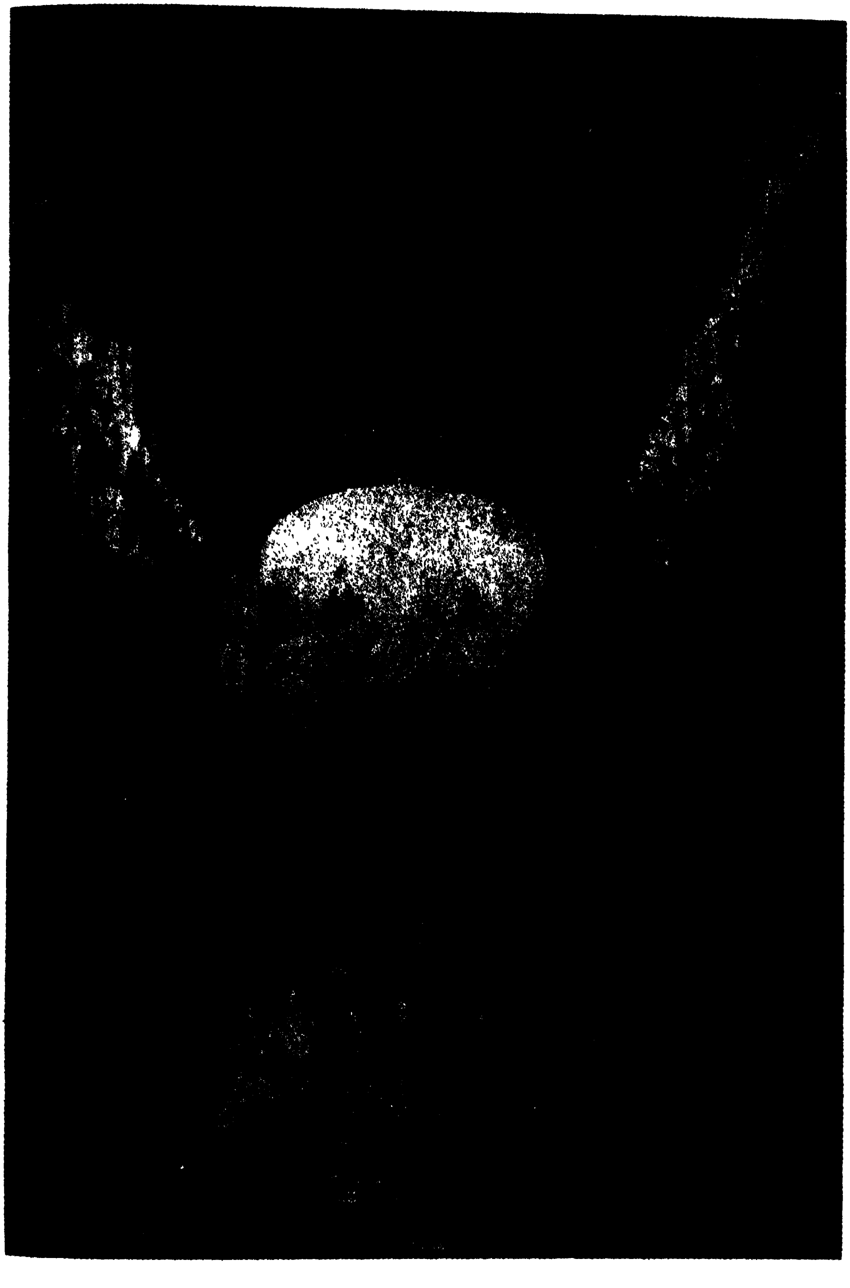
PLATE II



AMARAVATĪ: DECORATED ENCASING DRUM-SLAB

PLATE III



ELLORĀ: CAVE 10—STŪPA WITH BUDDHA FIGURE INSIDE

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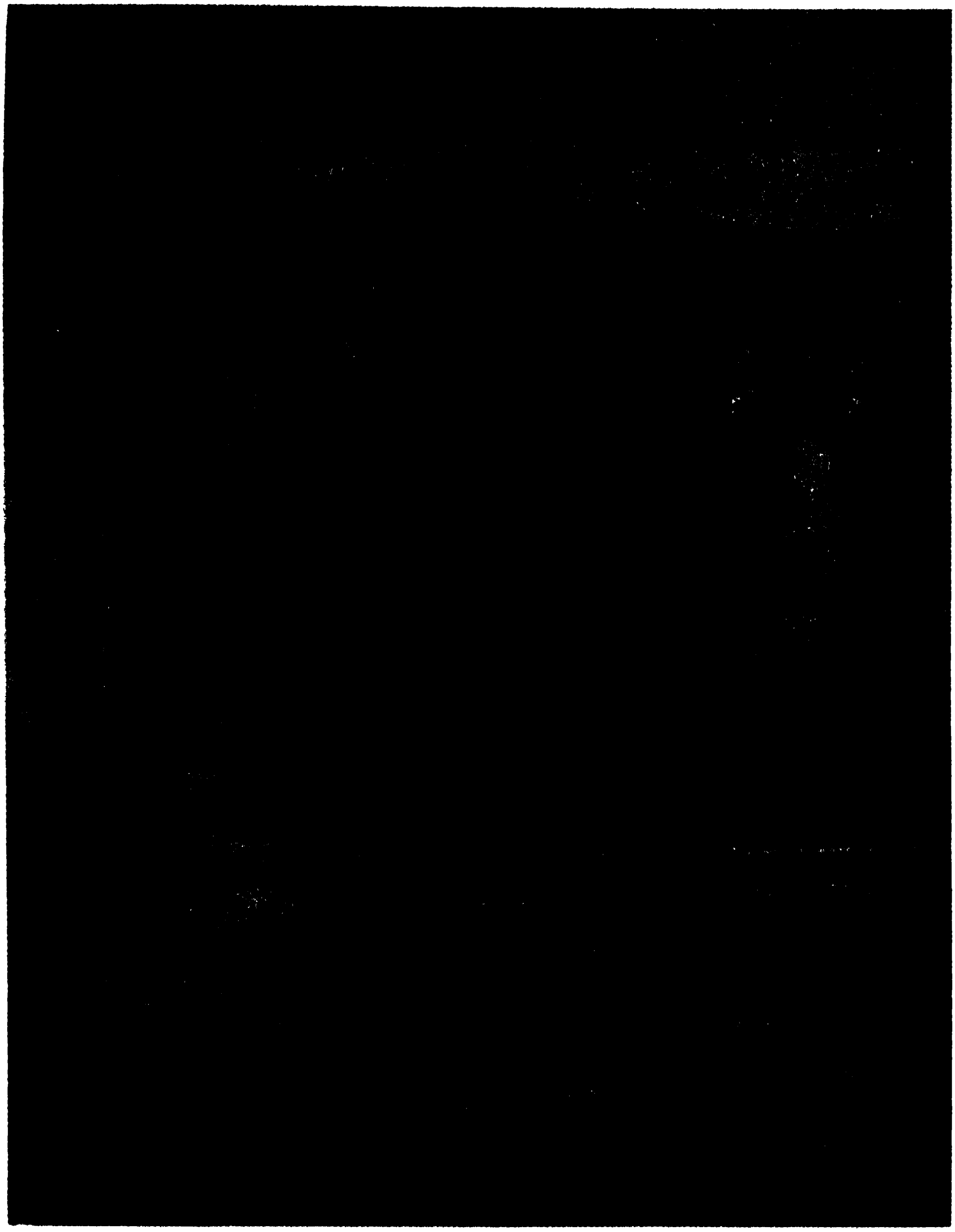
PLATE IV

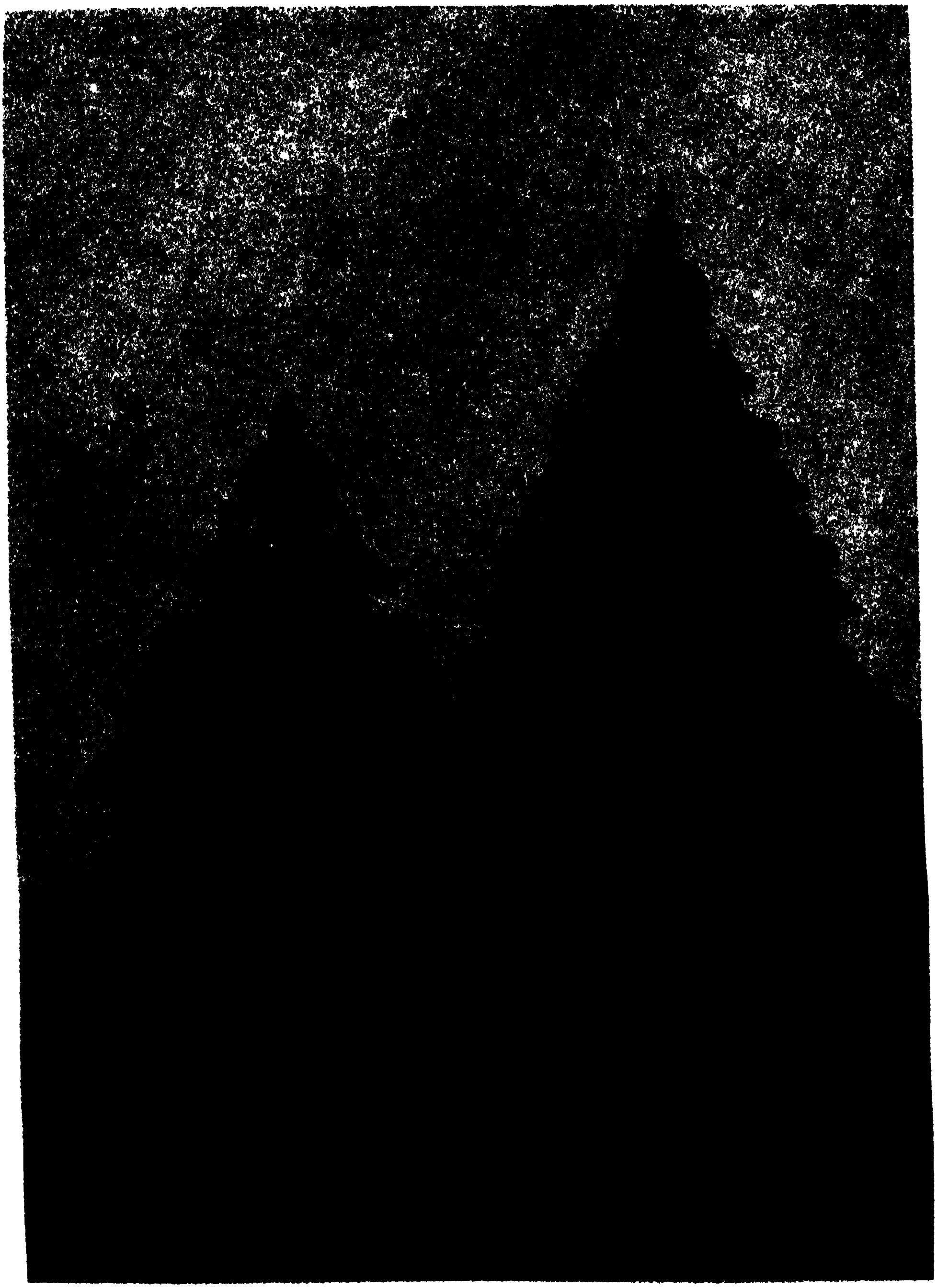


SĀÑCI: EARLY GUPTA TEMPLE

PLATE V

RODA: POST-GUPTA PERIOD TEMPLE

PLATE VI

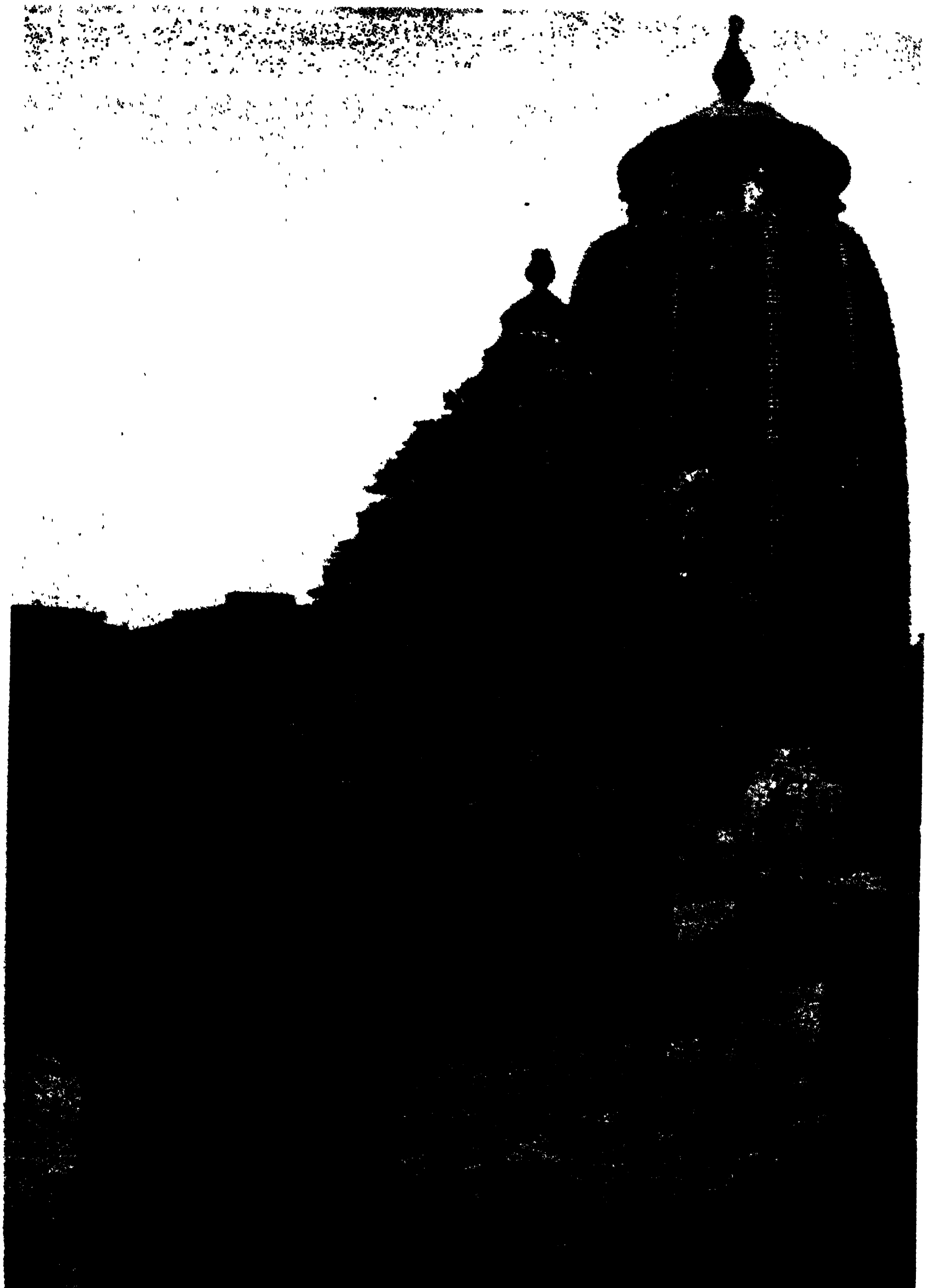


MAHABALIPURAM: SHORE TEMPLE

PLATE VII

TIRUVANNAMALAI: *GOPURAMS* WITH TEMPLE ENCLOSURES

PLATE VIII



BHUVANESWAR: LINGARĀJA TEMPLE

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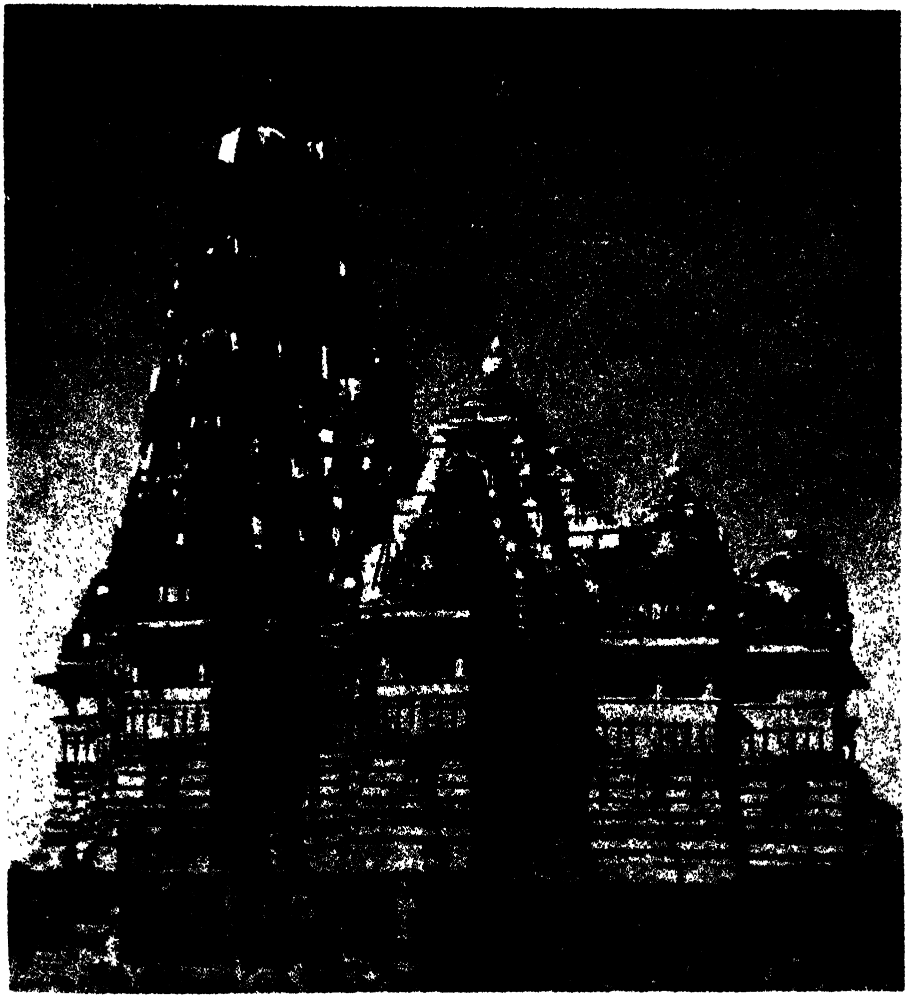
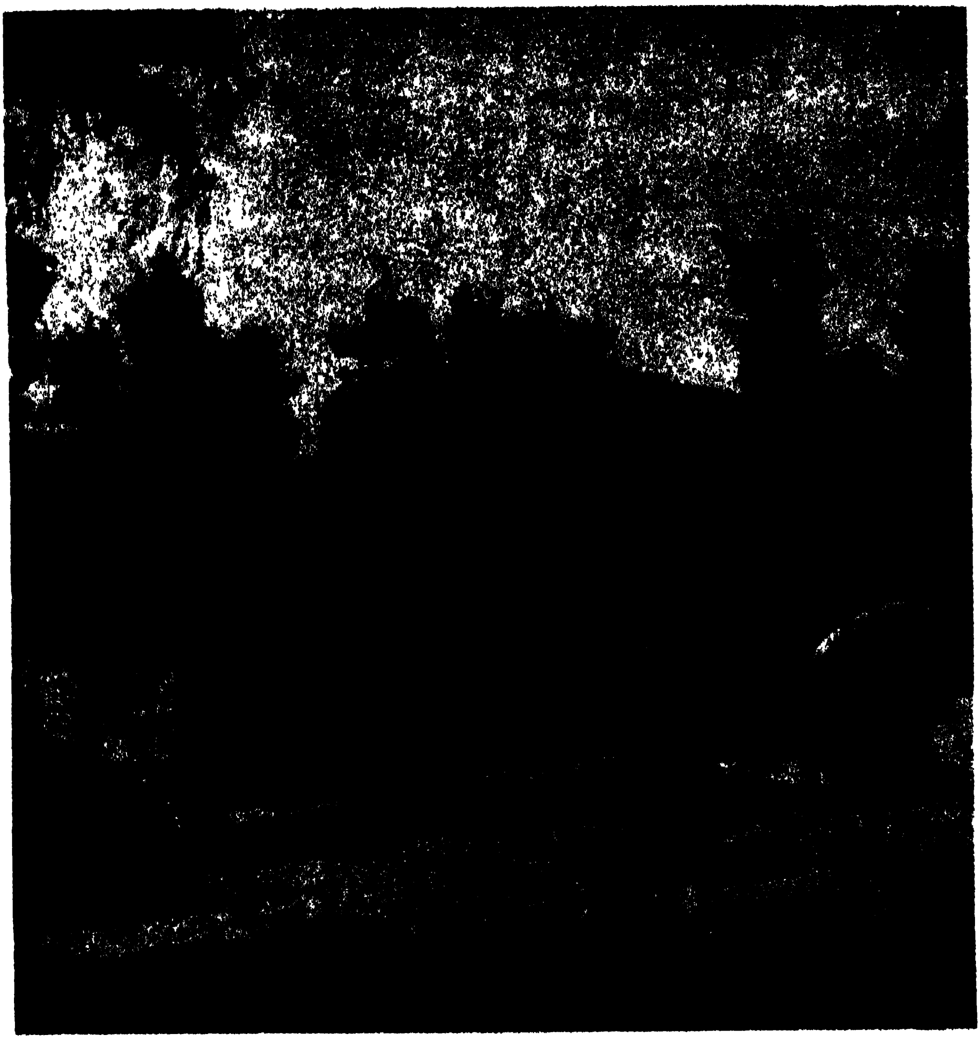
PLATE IX



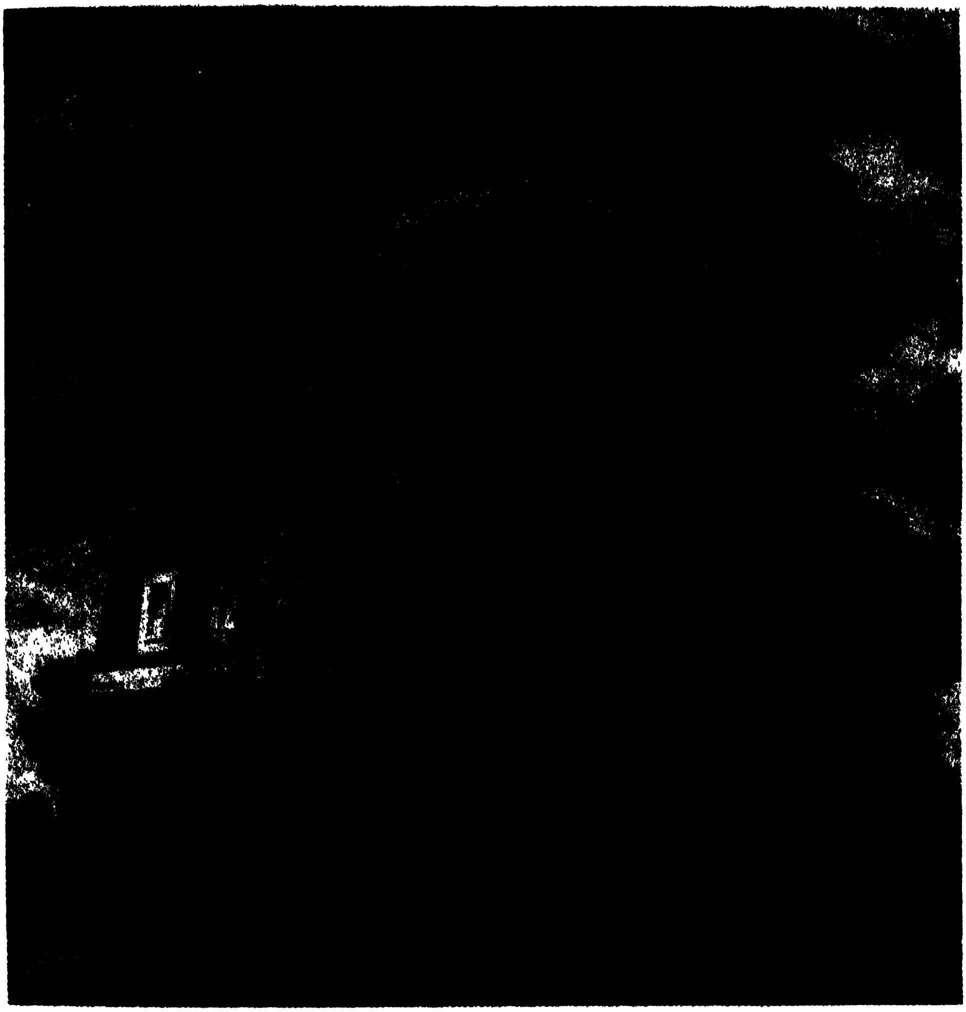
KHAJURAHO: KANDĀRIYĀ-MAHĀDEVA TEMPLE

PLATE X



MAHABALIPURAM: PĀNDAVA RATHA HEWN OUT OF BOULDERS

PLATE XI



DELHI: GHIYĀS-UD-DĪN TUGHLUQ'S TOMB

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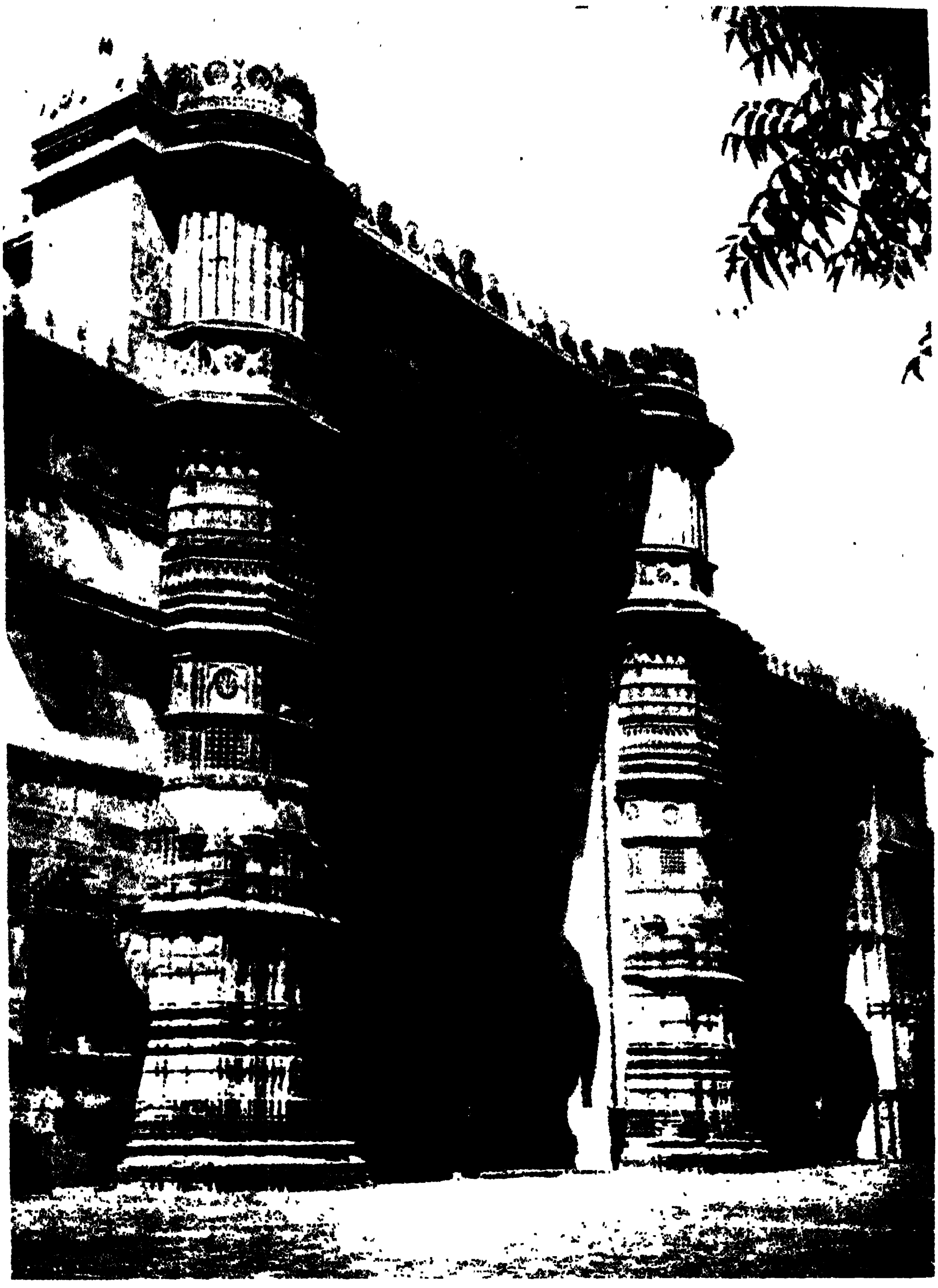
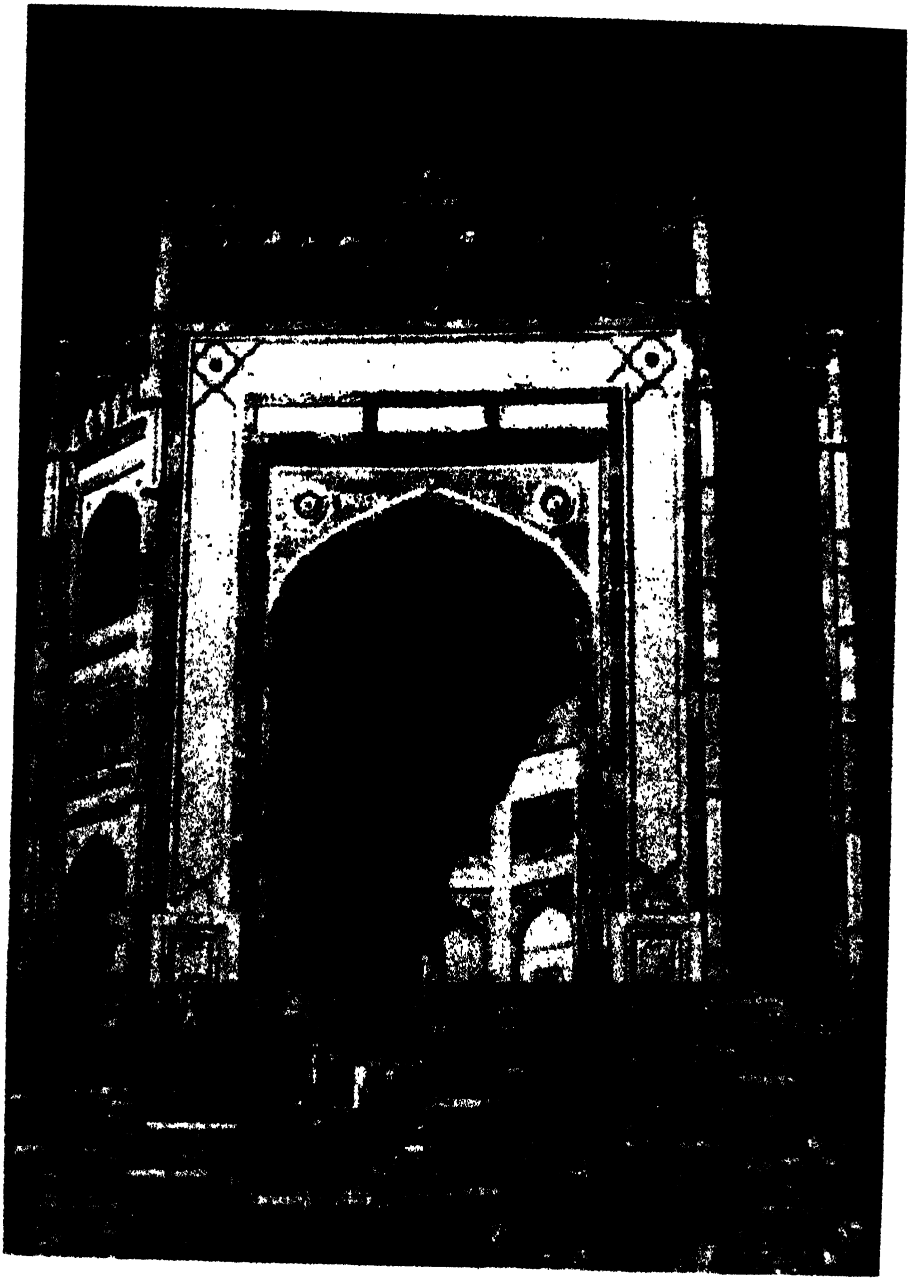


AHMEDABAD: GATEWAY OF JAMI'MASJID

PLATE XIII

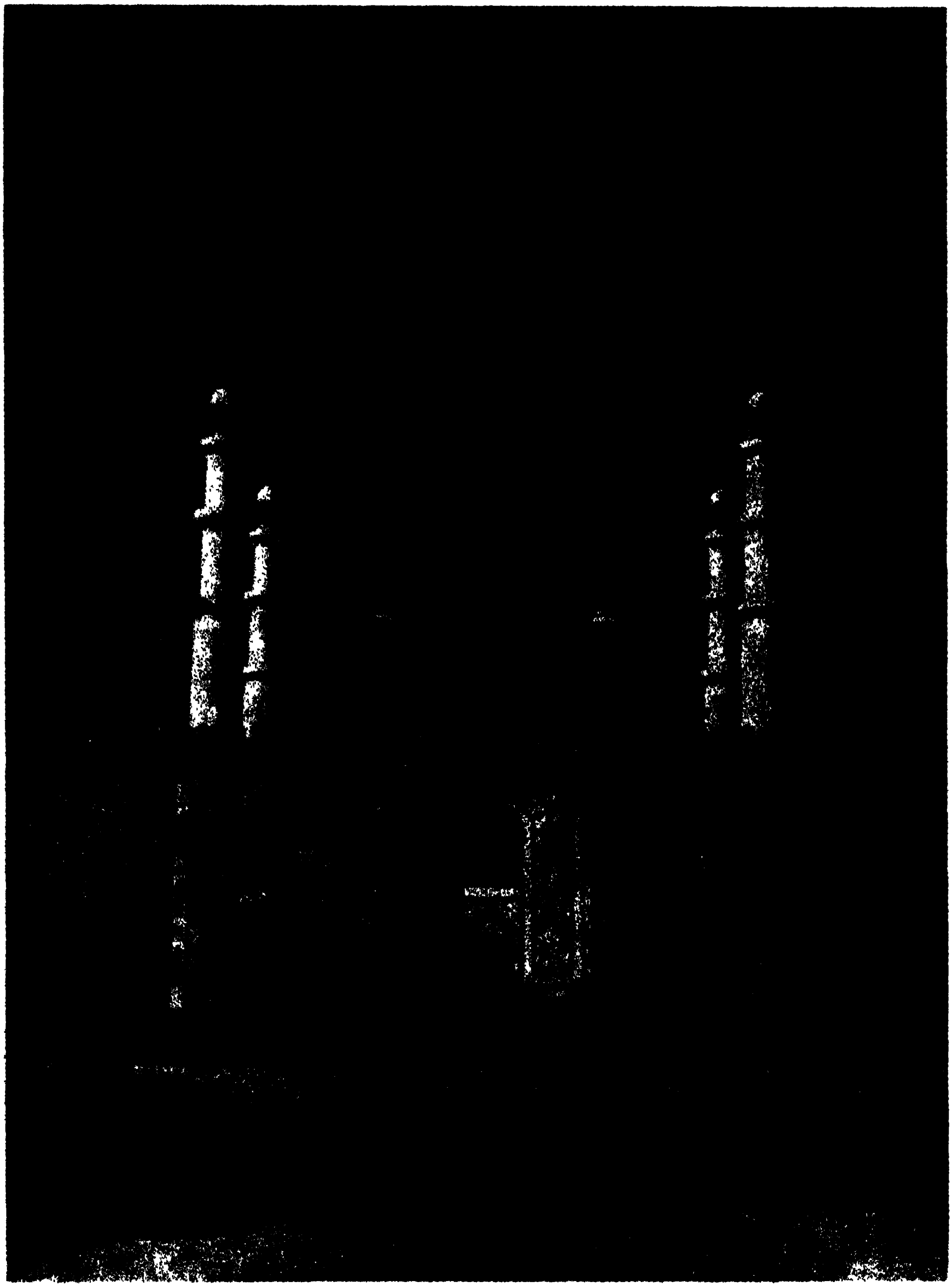
BIJAPUR: IBRĀHĪM-ROUZA

PLATE XIV



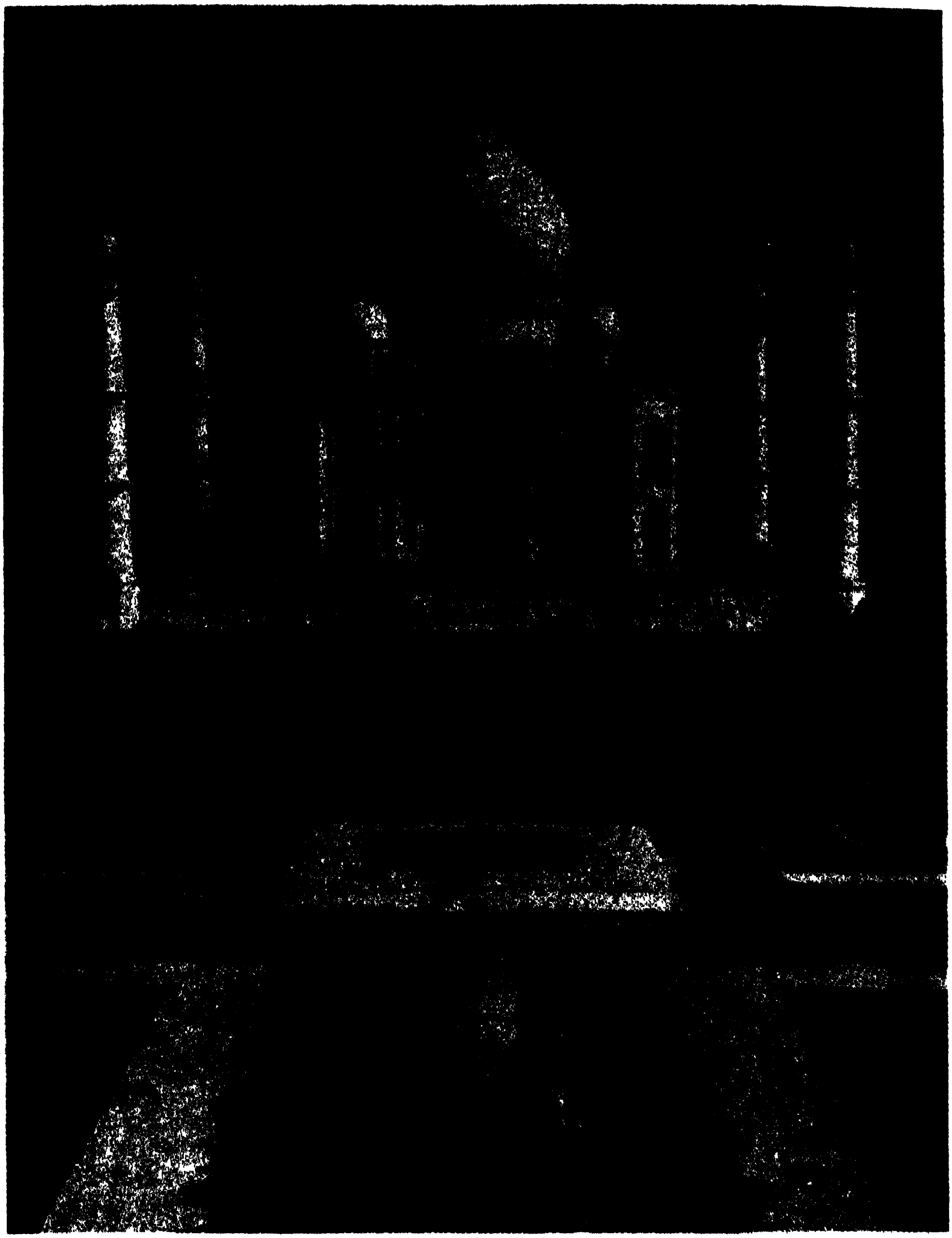
FATEHPUR SIKRI : BULAND DARWĀZA

PLATE XV



AGRA: GATEWAY OF AKBAR'S TOMB

PLATE XVI



AGRA: THE TĀJ MAHAL

rope pulleys on scaffolding. Ramps of timber or sand were built on which to haul up exceptionally large stone slabs.

The Jaina temples did not have any distinct form of architecture. In later days the Jains built up a large number of temples in a rather unplanned manner at the sacred hills like Girnar (Junagarh district) and Śatruñjaya (Bhavnagar district). Nonetheless, the Dilwara temple at Mount Abu and the temple of Neminātha do evoke appreciation, the former especially for its intricately carved sculptures.

The later temples of Bengal are characterized by a simple curved roof, imitating the bamboo-and-thatch constructions of the region. The Vishnupur (Bankura district) temples belong to this type. There are still other popular types of miniature shrines grouped in tiers to form five- or nine-spired (*pañca-* or *nava-ratna*) shrines.

ROCK-CUT ARCHITECTURE

The rock-cut temples, both cut in and out of the rock, mostly followed the contemporary architectural styles. The earliest group of such temples excavated by Aśoka in the Barabar and Nagarjuni hills (Gaya district), depicts the basic forms of rock-cut architecture. Subsequent rock-cut shrines, especially those of the Buddhists in western India at Bhaja Kondhane, Pitalkhora, Ajantā, Junar Karle, and Junagarh, were fashioned in imitation of the earlier wooden constructions. Among the monasteries, the two double-storeyed ones at Ellorā are the largest. Brāhmaṇical caves are at their best at Badami, Ellorā, Elephanta, and Mahabalipuram with a profusion of beautifully carved-out sculptures. At Mahabalipuram huge granite boulders have been chiselled to various shapes (Plate X).

The Kailāsa temple at Ellorā (*c*. A.D. 800) stands unparalleled as a monument to the artistry and craftsmanship of Indian rock-cut architecture. Brown describes it as 'the most stupendous single work of art executed in India'.[17] The temple of Kailāsa was executed by cutting away more than fifty million tonnes of rock from the sloping hill by means of hammer and chisel, a process which took some 100 years. The first step was to cut three trenches at right angles into the hill, thereby isolating a massive block of stone over 60 m. long, 30 m. wide, and 30 m. high. Next, this block was carved from the top downwards and hollowed out into the form of the temple with its intricate carvings. In order to highlight the shape of the temple against the grey stone of the mountain surrounding it, the entire edifice was coated with a white gesso, imparting to it a brilliant sheen.

The Jains too carved out retreats in the hills of Udayagiri and Khaṇḍagiri

[17]Percy Brown, *Indian Architecture—Buddhist and Hindu Period* (Bombay, 1942), p. 90.

near Bhuvaneswar in the first century B.C. and shrines later at Ellorā, Badami, and elsewhere.

INDO-ISLAMIC ARCHITECTURE

The Muslims brought with them new building traditions and forms of expression. The flat lintels or corbelled ceilings were replaced by arches or vaults and pyramidal roofs or spires by domes. Sun-shade or *chajja* fixed into and projecting from the wall, kiosks on the roof, tall towers, and half-domed portals are some of the distinctive features of architecture which came into vogue with the Muslims in India. Introduction of the new style was not, however, universal. Muslim architecture with the associated technique and skill flourished while mingling with the prevailing Hindu style which, again, varied from region to region.

In Delhi itself one can see the development of different forms under the five different Muslim dynasties until the Moguls assumed power. The Mamluks or the Slaves (1206-90) had to their credit the Quwwatfl-Islām mosque, the imposing Qutb Minār, and the first monumental tomb in India, Sultan Ghuri's tomb. But it is only during the time of the Khaljīs (1290-1321) that Indo-Islamic architectural traits, obviously of Seljukian flavour, like the low dome, red sandstone facing with white marble bands, and 'spearhead' fringe on the underside of the true arch are noticed in the Alāī Darwāza in the Qutb complex and Jamā 'at-Khāna Masjid which influenced later constructions. Thus in spite of the plain and austere surface of grey stone introduced by the Tughluq rulers (1320-1413), Ghiyās-ud-dīn's tomb (Plate XI) still retained the red sandstone and marble facing, though vaults over large halls, battered walls, conical domes, etc. mark further innovations. Again, the tomb of Khān-i-Jahān Tilangānī with an octagonal chamber covered by a dome and enclosed by a verandah, each side of which is pierced by three arches, later influenced the tombs of Mu'iz-ud-din Mubārak Shah and Muḥammad Shāh of the Sayyids (1414-51) and that of Sikandar Lodī. The Lodīs (1451-1526) in their turn introduced in the two mosques of Barā Gumbad and Moṭh-kī-masjid new features in dividing the prayer chamber into five bays surmounted by three domes resting on corbelled pendentives and the terminal bays being roofed by low vaults. These features, along with a wall-mosque in a garden enclosure as in Sikandar Lodī's tomb, were further developed in the Mogul period.

The contemporary architectural styles of the Delhi Sultanate were broadly followed in their provincial kingdoms of Gujarat, Bengal, Malwa, Jaunpur, Deccan, Khandesh, and Kashmir. The Gujarat style emerged as the richest and probably the most prolific, the Deccan style being remarkable for its bold conception and variety of forms. If the Jāmi'Masjid at Cambay (1325) represents the earlier work, the Jāmi'Masjid (1423) at Ahmedabad (Plate XII)

with prominent minarets denotes its transitional period. One can see the flowering of this style in such examples as the mosques of Muḥāfiz Khān (1492), Rānī Sīprī (1519), and Sīdī Said' (1572), all famous for beautiful workmanship. In the Deccan, the Jāmi'Masjid (1362) at Gulbarga is unique in having a roofed courtyard. The college building of Khwāja Maḥmud Gāwān (1422) at Bidar with its tall bulbous domes, glazed tiles on the walls, etc. is almost entirely Persian in conception, and the royal tombs there with stilted domes are noteworthy. In Bijapur the bulbous dome with the drum concealed behind a row of petals, four-centred arches with low piers, and slender minarets adorn Ibrāhīm-Rouza (Plate XIII), Mihtar Maḥal, etc. But by far the *magnum opus* is the tomb of Muhammad 'Ādil Shāh (1627-57) known as Gol-Gumbad, having the largest dome cubicle in the world and famous for its acoustic property.

The form of the Lodī octagonal pattern was further improved upon and developed in Sher Shāh's tomb (*c.* 1540) at Sasaram having pillared domes and matching pillared kiosks on the terraces. It rises with a thirty-two sided base for the crowning dome. The Qil'a-i-Kuhna Masjid inside the Purānā-Qil'a at Delhi anticipated the early Mogul mosques and, unlike the plain tombs, was decorated with coloured marble and ornamental designs.

The contribution of the Moguls of Timurid traditions in the history of Indo-Islamic architecture remains unparalleled. Encased with red sandstone or marble, their buildings are remarkable in conception, beauty, and symmetry. Their earlier construction, the Jamāli-Kamali-Masjid, is traditional in concept. Humāyūn's tomb, set in a garden enclosure, has Persian elements like arched alcoves, corridors, and the high double dome. Akbar's buildings at Fatehpur Sikri like the Jāmi'Masjid with the majestic Buland Darwāza (Plate XIV), the unique Dīwān-i-Khās, and the exqusitely carved houses of Turkish Sultanā and Birbal are the results of a happy blending of indigenous and Islamic modes. At Agra the imposing gateway to Akbar's tomb (Plate XV), profusely decorated with inlay works as also seen in the finely carved marble tomb of I'timād-ud-daulāh having four corner minarets, set a new trend which considerably influenced the technique employed in constructing the Tāj Maḥal (Plate XVI). Shāh Jahān's buildings are noted for their foliated arch; dome, bulbous in outline and constricted at the neck—a typical Timurid feature; and greater use of marble. The Moti-Masjid in the Agra Fort; the incomparable and unique Tāj Maḥal with its garden; the largest mosque in India, the Jāmi'Masjid of Delhi; and the Red Fort in Delhi—all testify to his creative zeal and passion for building edifices. The decline is indicated in the Bībī-kā-Maqbara, a replica of the Tāj Maḥal at Aurangabad, while the tomb of Safdar-Jang marks the last phase of Mogul architecture of the pattern set by Humāyūn's tomb.

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INDIA AND THE ANCIENT WORLD: TRANSMISSION OF SCIENTIFIC IDEAS

IF one looks at the map of the ancient world one cannot but be impressed by the geographically central position of India. The country is situated between the earliest river valley civilizations of Egypt and Mesopotamia on the west and China on the east. Bounded on the south, south-east, and south-west by a vast ocean and the seas and on the north, north-west, and north-east by massive mountain ranges marked by some of the highest peaks of the world, India enjoyed a degree of protection and isolation unique in the world. Yet its mountain passes, breaking through the great barrier at a number of places, particularly on the north-western frontier, provided a natural access to Afghanistan, Iran, the Pamir, and Central Asia and from there either to West Asia and the Mediterranean world or to Turkistan and China. Several mountain tracks which could be negotiated either on foot or on yaks and other beasts of burden were the only means available for commercial, cultural, and scientific communication with the tableland of Tibet. The more formidable mountain barrier on the north-east, while effectively discouraging easy movement of peoples, ideas, and goods, could not completely exclude some form of contact between India and China.

From very early times India was aware of these geo-economic features which tended, on the one hand, to isolate the country and encourage its own cultural pattern and, on the other, to provide a strong motivation to break this isolation through trade and other international exchanges.[1] The awareness of these geo-economic features along with their advantages and disadvantages is reflected in a number of passages of the *Ṛg-Veda*, *Atharva-Veda*, Buddhist *Jātakas*, and *Arthaśāstra* of Kauṭilya.[2]

It is not surprising, therefore, that India's commercial and cultural contacts with Central Asia, West Asia, and Egypt should extend to prehistoric times. Badakhshan's lapis lazuli and Central Asian jade found their way

[1]S. N. Sen, 'Trade Routes and the Transmission of Scientific Ideas between India and Central Asia', paper read at Indo-Soviet Seminar in Bombay in November 1981 under the auspices of the Indian National Science Academy.

[2]*R. V.*, X. 144; and *A. V.*, XII, I, II mention geographical features. About the skill and daring of Indian merchantmen, *vide R. V.*, I. 25. 7; 56.2; 97.7; 116.3; VII. 88.3. For periodical commercial voyages to Bāveru or Babylon, see *Bāveru Jātaka* (E. B. Cowell, *The Jataka*, Vol. III, Luzac and Co. Ltd., London, 1957, p. 83). See also R. Mookerjee, *Indian Shipping* (Longmans, Green and Co., 1912), pp. 29-30. Kauṭilya lays emphasis on geo-politics and geo-economics by using such expressions as *cakravarti-kṣetra*.

to Indus cities in the same way as they did to Sumer and other ancient centres in the fertile crescent. In historic times, the Achaemenian empire and the Graeco-Bactrian kingdoms provided an effective bridge between India and the Mediterranean world. 'In the sixth century B.C.', writes Bevan, 'the Semitic and other kingdoms of Nearer Asia disappeared before a vast Aryan Empire, the Persian, which touched Greece at one extremity and India at the other.' Tributes from Ionia and the frontier hills of India found their way into the same imperial treasure-houses at Ecbatana or Susa. Contingents from the Greek cities of Asia Minor served in the same armies with levies from the banks of the Indus. From the Persian the name Indoi, Indians, now passed into Greek speech. Allusions to India begin to appear in Greek literature.[3] By the beginning of the Christian era Ptolemaic Egypt and Rome's eastern empire had established thriving commercial relations with India. The Indo-Roman trade was specially stimulated by the discovery of a new method of navigating the high seas with the help of the monsoon wind. The Sino-Indian intercourse partly depended on trade along the silk roads through the heartland of Central Asia with branch routes passing through India, but developed more significantly as a result of the spread of Buddhism to China.

TRADE ROUTES

Before we deal with the travel of scientific ideas following the establishment of commercial and cultural relations, it would be worthwhile considering the development of trade routes by land and sea.

Overland Routes: A national highway spanning the whole of northern India from Manipur in the north-east to Puṣkalāvatī or Puruṣapura near Peshawar (now in Pakistan) had probably existed from the beginning of historical times. This highway, then generally known as the *uttarapatha*, and designated NH-1, passed through Mahāsthāna, Gauḍa, Puṇḍravardhana, Bhukti, Vaiśālī, Kuśīnagara, Kapilavastu, Śrāvastī, Ahikṣetra, Indraprastha, Takṣaśilā, and Puṣkalāvatī.[4] One link road to this national highway connected Gauḍa, Tāmralipta, and Patna. The NH-1 was further reinforced by an almost parallel highway, NH-1A, which passed through Gaya, Kāśī-Prayāga, Kanauj, Saṅkāsya, Soron, and Indraprastha. From Indraprastha a branch road dived towards Bolan pass connecting Agroha, Śirṣa, and Mūlasthāna (Multan) and another highway took a turn towards the south passing through Mathurā, Ujjayinī (Ozen of the Greeks), Minnagara, and Broach (Barygaza) on the Arabian Sea. Thus were Takṣaśilā and Puruṣapura on

[3]E. R. Bevan, 'India in Early Greek and Latin Literature', *The Cambridge History of India*, Vol. I (second Indian reprint, 1962), pp. 351-52.

[4]Prakash Chand Prasad, *Foreign Trade and Commerce in Ancient India* (Abhinav Publications, New Delhi, 1977), p. 108.

either side of the Indus linked with Tāmralipta commanding the maritime trade of the Bay of Bengal, with Barbaricon (modern Karachi) at the mouth of the Indus, and with Minnagara and Broach, important trading posts on the Arabian Sea in the ancient world.

It is obvious that Takṣaśilā, by virtue of her strategic geographical position as well as her status as the capital city of Gāndhāra, played a leading part in the inland and foreign trade of ancient India. It was not only the terminus of several major inland trading routes, but the starting point of all great routes seeking to connect India with the outside world beyond the mountains. Thus one route went towards the north through Srinagar in the Kashmir valley, to Gilgit, Yarkand, Kashgarh, and other parts of eastern and western Turkistan. The most important western route passed through Puṣkalāvatī, Puruṣapura and Kapiśa to Bactria. This route rose to great importance during the Achaemenian period when the Punjab was one of its satraps and again during the Seleucid period when it served as the royal highway to West Asia.

Situated at the entrance of the all-weather Khyber pass, Puruṣapura was indeed the gateway to India. Kapiśa has been identified with modern Begram at the junction of Panjahir and Ghorband. According to Foucher, the oldest and the most frequented route from Kapiśa to Bactria ran through Bamyan and a number of passes such as Robat, Dandan, Shikan, and Karakotal and then followed the river Dana Yousouf to reach Bactria through Mazar-i-Sarif.[5] Hiuen Tsang, after reaching Bactria from Samarkand, followed this route through Bamyan and Kapiśa and descended to Puruṣapura (in Gāndhāra) through the Khyber pass.

Around the second century B.C. Bactria developed into an international trading centre and, more particularly, into a clearing mart for Indian goods. It was the natural converging point of several routes, namely, the Babylon-Bactria and Susa-Herat-Bactria international highways from the west, the Tashkent-Samarkand-Bactria highway from the Oxus valley on the north, and a number of routes from Kashgarh on the west. The western route from Bactria first dived south-west towards Herat (also known as Alexandrcia Areion), struck north towards Antiokheia Margiana (modern Merv in Turkmenistan in the U.S.S.R.) and then followed a more or less westerly course through Hyrkania (modern Gurgan in North Iran), Hekatompylos (the old Parthian capital), the Caspian Gates (a narrow pass in the Elburz mountains), Ragae, and Ecbatana (modern Hamadan). From Ecbatana one can easily reach Seleucia-Ctesiphon on the Tigris, below modern Bagdad. Zeugma, a Greek city on the right bank of the Euphrates, lies about 555 miles

[5] A. Foucher, *Notes on the Ancient Geography of Gandhara* (trans. Hargreaves); see also '*La Vieille Route de l'Inde de Bactres à Taxila* (*Mem. de la Delag, Archeol. Franc. en Afganistan*, Paris, 1940-47).

north-west of Seleucia-Ctesiphon; from Zeugma one can proceed to several Mediterranean ports such as Antioch, Tyre, and Sidon.

In prehistoric times Iran and India were connected by other international highways linking Quetta with either Ecbatana or Susa. The former route originating at Quetta ran through Kandahar (Alexandropolis), Phra (modern Farah in Afghanistan), Herat, Nishapur, Subzawar, Qum, and Ecbatana. The latter, pursuing a southern and central route, passed (after Kandahar and Phra) through Helmand, Tell-i-Blis, Kirman, and Persepolis (the spring capital of the Achaemenian empire) and ended at Susa.

Starting from Bactria, there were two routes going to the Oxus valley—one towards the Caspian Sea and the other towards Tashkent via Samarkand. The former, sometimes known as the Caspian highway, has been mentioned by Strabo, Pliny, and other ancient geographers. This route found favour with the Indian traders desiring to send their merchandise to the Black Sea ports. According to Strabo, 'the river Oxus is so easily navigable that Indian merchandise. . .is easily brought down to the Hyrcanian sea and then on the rivers to the successive regions beyond as far as Pontus'.[6] The route to Tashkent going farther north-east to Turfan passed through Samarkand or Marachanda where Alexander suffered a military disaster. Alexander nevertheless marched up to Khojend, then known as Alexandria *Eschate* (the farthest). About 150 miles north-west of Khojend lies modern Tashkent, capital of Uzbekistan (U.S.S.R.) and famous for its stone tower. There was at one time a controversy about the association of this historic stone tower with Tashkent or Tashkurghan near the Pamirs (also famous for a stone tower) which has been settled in favour of the former on the basis of Ptolemy's description and latitudes. From Tashkent the route runs through the northern parts of the great Tien Shan mountain range, connecting cities like Kulja, Uranchi, and Turfan.

Like Bactria and Samarkand, the city of Kashgarh farther west is another important trading post which rose to prominence along with the development of silk route and silk trade in general. This city lies on the western fringe of the great Taklamakan desert in between the Tien Shan range on the north and the Kun-lun mountain range on the south. The desert, also known as the Tarim basin, is a trough-like oval, the outer periphery of which is stringed by a series of oases. Accordingly, two routes emerged from Kashgarh—one going through the southern periphery of the desert on the northern foot-hills of the Kun-lun, and the other following the northern periphery south of the Tien Shan. The southern route embraced such important places as Yarkand, Karghalik, Keriya, Niya, Endere, Charchan, Charkhlik, and Miran, skirted the salty Lop-nor marsh, and proceeded to Tung-huang and An-hsi. The

[6] Prasad, *op. cit.*, p. 145, quoted from Strabo, II. 1.15; XI. 73.

northern route from Kashgarh passed through Uch-Turfan, Aksu, Kucha, and Korla; from Korla one route turned south-east to pass through Kuruk Darya, Lou-lan, and other places terminating at Tung-huang, and another route turned north-east to encompass Karashahr and Turfan and made a great arch through Hami, finally ending at An-hsi. Turfan was an important junction where the Tashkent-Kulja-Urunchi route met the Aksu-Kucha-Karashahr road. In his forward journey to India Hiuen Tsang followed the Hami-Turfan-Tashkent-Samarkand road and descended from the Oxus valley to Bactria to make his way to India through Bamyan, Kapiśa, and Puruṣapura.

Kashgarh can also be reached from Bactria by a route going south of the Pamirs. This route leads to Badakhshan up the open valley of Wakhan, then to Sariqol south of the peak Muz Tagh Ata, to the capital city of Tashkurghan, finally sloping down the barren hills to the oases of Kashgarh and Yarkand. This route was negotiated by Hiuen Tsang in A.D. 644 on his return journey to China and by Marco Polo on his famous journey to Cathay in A.D. 1273. The Badakhshan-Wakhan-Sariqol road could also be approached from the Kashmir valley through Gilgit, Darkot, and Baroghil passes, meeting the main road at Sarhad.

The routes through the Tarim basin which established a direct link between China and India and West Asia through western Turkistan played an important role in the Chinese silk trade as well as in the transmission of many scientific and technological ideas in the ancient and medieval times. The opening of these overland silk roads was due to the efforts of the enterprising Chinese diplomat Chang Chhien whom Needham has called a 'Seric Livingstone'.[7] Alexander in his effort to penetrate into Central Asia could never get beyond Samarkand or Khojend as already noted. The Bactrian kings, notably Euthydemus, tried to achieve this feat by a road north of the Tien Shan, but without success. In the second century B.C., due to the forward diplomatic and military policy pursued by Emperor Wu Ti, Chang Chhien was able to strike this route through the Tarim basin and reach Sogdiana and Bactria. He could not follow a northerly course beyond the Tien Shan because of the hostilities with the Huns. These diplomatic-cum-geographical explorations proved of inestimable value in the exchange of cultural and scientific ideas, because the Tarim basin itself developed as a meeting-ground of people from many countries.

Sea Routes: Archaeological finds from Ur, Harappa, and Mohenjo-daro already pushed back the antiquity of India's relations with West Asia to the third millennium B.C., when ancient Indus cities were without doubt in regular and intimate contact with Sumerian cities in Iraq. That a good

[7] J. Needham, *Science and Civilisation in China*, Vol. I (1961), p. 176.

part of this commercial relationship was established through maritime activity along the Persian Gulf is attested by an extensive literature dug up in the cities of Mesopotamia. This literature describes regular trading voyages down the Persian Gulf from Ur, Larsa, Lagash, and Nippur to the trading posts of the kingdoms of Dilmun, Makan, and Meluhha.[8] Meluhha was long suspected to be a city in the Indus valley (Mohenjo-daro ?). That the suspicion was not without foundation has been proved by recent archaeological excavations carried out in the island of Bahrain by the Danish Prehistoric Museum of Aarhus.[9] Bahrain now appears to be identified with the legendary Dilmun of cuneiform records, which served as a great intermediate emporium in the trade between Sumer and the Indus valley. Excavations at Ras al-qala and several other sites in the coastal line of Trucial Oman have revealed pre-Christian trading posts engaged in a lucrative trade between India and West Asia.

Coming to historical times, we hear of a geographical expedition headed by the Greek mercenary Skylax of Karnyanda who, under the orders of the Persian emperor Darius, navigated down the Indus, explored its source, and found a way to the Red Sea by following the coast of Arabia. In the second century B.C., in the time of the Ptolemies, another Greek geographer, Eudoxus of Cyzicus, attempted a long-distance voyage from Egypt to India. Interestingly enough, this Eudoxus, who is mentioned by Strabo, conceived of the idea of going round the continent of Africa with a view to reaching India from Europe. The Ptolemies who encouraged the navigational efforts of Eudoxus had long-term plans for the development of a large number of Red Sea ports to facilitate navigation in this part and ultimately in the wider Indian Ocean. Thus Ptolemy Philadelphus (285-246 B.C.) caused a large port to be built at Arsinoe (modern Suez) and later on at other places like Berenice and Myos Hormos. Both Berenice and Myos Hormos were connected to Coptos (Keft) on the Nile by caravan routes over the desert. These ports helped the Egyptian, Greek, and later Roman sea-faring merchants to trade with Adulis and other ports on the African coast and with Muza, Ocelis, Arabia Eudaemon (modern Aden), Cane, and Moscha, all on the Arabian coasts. All these ports were famous for Indian goods which used to be shipped there regularly by Indian and Arabian traders despite Afro-Arabian trade monopolies built up from very ancient times. These monopolies were held by the Somalians with their capital at Auxum and port at Adulis, the Sabaeans with their capital at Ma'rib, and the Nabataeans with their

[8] A. L. Openheim, 'The Sea-faring Merchants of Ur', *Journal of American Oriental Society*, LXXIV (1954).

[9] S. N. Sen, 'Transmission of Scientific Ideas between India and Foreign Countries in Ancient and Medieval Times', *Bulletin of the National Institute of Sciences of India*, No. 21 (1962), p. 11.

capital at Petra. These Sabaean and Nabataean traders were possibly involved in the transmission of Semitic scripts, the development of the Brāhmī, and the spread of the Indian decimal place-value notation in different historical periods.

Towards the end of the first century B.C. Rome's eastern trade received a new impetus from the vigorous policies pursued by Augustus. About this time the Sabaeans were subdued, the Nabataean piracy in the Red Sea was contained, and the Ethiopian trade was cut to size. The result of all this was the sudden increase in Egyptian shipping in the Red Sea-Indian Ocean area, about 125 ships making regular annual voyages to Indian ports. But the most important contributory factor in this increased shipping was the discovery of the secret of navigation of the high seas with the help of the monsoon wind. The discovery detailed in the *Periplus* is generally associated with the name of a Greek mariner, Hippalos, but it was possibly the discovery of a secret already held by the Afro-Arabian sailors. The discovery was that if the sailors could leave Bab-al-Mandab in the month of July, they could throw the ship's head off the wind with a constant pull on the rudder sail along the arc of a circle, and reach the Malabar coast in India in forty days.[10] This shortening of the route to India led to an enormous increase in Rome's Indian trade, as corroborated by the discovery of hoards of Roman coins in gold and silver in many places of the Coimbatore district (Pollachi, Vellalur, Karur).[11]

ARTICLES OF TRADE

The *Periplus* is not only an important document for the navigation of the Indian Ocean around the first century B.C., it also provides valuable information about the many commercial products of vegetable and mineral origin which then entered into this east-west trade. Warmington analysed *Periplus*'s descriptions of a large number of these products of which special mention may be made of the following:[12]

(i) Pepper (Tamil *pippali*), specially the black variety, P. nigrum, formed the most important article of export from the Malabar and Travancore coasts. Pepper was valued largely for its medicinal properties—remedy for agues and fevers—and was frequently described by leading Roman authorities like Pliny, Celsus, Galen, and Scribonius. It is no wonder that Alaric demanded 3,000 pounds of pepper from Rome (A.D. 408) as one of his terms.

(ii) Ginger, *gingiber* or *zinziber* (Sanskrit *śṛṅgavera*, Tamil *inchiver*), another

[10] J. W. McCrindle, *The Commerce and Navigation of the Erythraean Sea*, trans. (Thacker, Spink & Co., Calcutta, 1879). See also W. H. Schoff, *The Periplus of the Erythraean Sea*, trans. (Longmans Green, New York).

[11] Sewell, 'Roman Coins Found in India', *Journal of the Royal Asiatic Society* (1904).

[12] E. H. Warmington, *The Commerce between the Roman Empire and India* (Cambridge, 1928).

vegetable product with many medicinal properties (mainly in helping digestive action), is mentioned in Dioscorides, Celsus, Pliny, and Scribonius.

(iii) Cardamoms, *Elettaria cardamomum*, which yields amomum and cardamomum, was chiefly used for purposes of medicines and perfumes. It grew in, and was exported from, Travancore, Malabar, Madura, Tinnivelly, and Dindigul.

(iv) Cinnamon was exported from India and China. The Arabian and Axumite traders kept it as a closely guarded secret. The Chinese cinnamon first travelled to India via Yunnan and Burma and possibly also through Tibet and Sikkim and then used to be exported from ports like Tāmralipta, Muziris, and Nelcynda.

(v) Oil of spikenard, *Nardostachys jatamansi* (Sanskrit *nalada*), extracted from a perennial Himalayan plant, was exported from Barbaricon, Barygaza, and the Malabar coast.

(vi) The root of Costus, *Saussurea, Lappa* (Sanskrit *kuṣṭha*), grown in Kashmir and in the basins of the Chenub and the Jhelum was an aromatic plant with medicinal properties.

(vii) Gum-resins (two varieties of *Boswellia thurifera*—the glabra and the serrata) were indigenous to Central India and the Coromandel coast. These were mentioned by Dioscorides, particularly as a remedy for tooth-ache.

(viii) Indigo, *Indigofera tinctoria*, was famous as a dyeing agent. It was grown in many places in India, used in ancient Egypt, and exported from Barbaricon.

(ix) Sugar (Sanskrit *śarkarā*, Prakrit *śakkhari*, Greek (*σακλαρου*) was used as a medicine and mentioned by Dioscorides and Theophrastus.

(x) Various ornamental and fragrant woods, e.g. ebony, teak, and sandal wood, were grown in the forest areas of Mysore, Kashmir, and other places.

(xi) Copper from Kulla, Garhwal, Nepal, Sikkim, and Bhutan was exported from Barygaza.

(xii) Iron and steel were important items of export from India. The use of Indian steel for making the finest sword was known from the time of Ctesias; Pliny's 'seres', sometimes interpreted to mean 'China', has also been interpreted as meaning the 'cheras' of the Malabar coast. The Greeks knew of Indian steel coming from Ariace (Gujarat) and had a special treatise on the tempering of Indian steel. Indian steel used to be imported into the Roman empire for making fancy cutlery and armour, particularly at Damascus and Irenopolis.

(xiii) Precious stones like diamond, quartz, opal, and pure crystallized silica formed important items of trade; the Indian skill of staining rock-crystals so as to produce the colour of precious stones was internationally known and mentioned by Pliny, Strabo, and Martial.

Indian names for a large number of commodities which prominently featured in this kind of trade naturally passed into the literature of West Asia and were also embodied in the Greek vocabulary. These words concern cotton, ivory, ebony, teak, sandal wood, black wood, tin, rice, cinnamon, ginger, and various spices, to mention a few. The words *sindu* for Indian cotton, the Hebrew *sadin* and the Greek σινδων were derived from Sanskrit. The Egyptian word *ebu* for ivory was likewise derived from the Sanskrit *ibha*. The Sanskrit *kastīra* for tin was transformed into κασσιτεροδ while Tamil *arissi* for rice, *karppu* for cinnamon, *inchiver* for ginger, and *pippalī* for pepper were almost transliterated into ορυζα (*aruz* in Arabic), καρπιον, ζιγγιβεριδ, and πεπερι respectively.

SPREAD OF PRAKRIT AND SANSKRIT

Prakrit and Kharoṣṭhī: Semitic influence following in the wake of commerce and industry is strongly indicated in the evolution of the alphabetical form of writing represented by Kharoṣṭhī and Brāhmī. Thomas, Cunningham, and Taylor successfully derived the Kharoṣṭhī script from the Aramic about the fifth century B.C. when the Achaemenians were in power. The language developed rapidly to receive the status of an official language in the imperial secretariat as well as in that of the satraps. After the extension of the empire into the Indian territory, the Persian satraps inducted Aramaean subordinates into Indian administration and encouraged the clerks of native rulers as well as village and town headmen to learn Aramic.[13] In the course of time, Aramic alphabet was adopted for north-western Prakrit, and then the characters of the alphabet themselves changed leading to the emergence of the Kharoṣṭhī script. The new script spread over north-west India, Afghanistan, and parts of Central Asia and remained current for about seven hundred years (fourth century B.C. to third century A.D.).

The use of Prakrit in Central Asia (U.S.S.R.) is attested by the discoveries in Tadzhikistan of an inscription dated *c.* first century B.C., an inscription in gold slab found at Dalverzin Tepe in Uzbekistan, and several inscriptions at Wardak and Qunduz in Afghanistan.[14] Some of the inscriptions are of uncertain date. Still more interesting is the discovery by late Sir Aurel Stein of hundreds of Kharoṣṭhī inscriptions, used in the context of Indian Prakrit, in several archaeological sites in the Tarim basin, in Khotan, Niya, Endere, Miran, Lou-lan, and Kurak-darya all on the caravan route skirting the Taklamakan desert. The script appears in a number of coins struck in or near

[13] G. Bühler, 'Indian Paleography', *Indian Antiquary,* XXXIII (1895); *Indian Studies* (1904).

[14] B. N. Mukherjee, 'Indian Literature Abroad—Central Asia (including Northern Afghanistan)', *The Cultural Heritage of India,* Vol. V (The Ramakrishna Mission Institute of Culture, Calcutta, 1978), pp. 706-7.

Khotan between the first century B.C. and the first century A.D. At Niya were unearthed over two hundred documents written in Kharoṣṭhī script and in black ink on all sorts of materials—wood, leather, paper, and silk. 'At the Niya site', writes Stein, 'I found by the hundred wooden documents comprising correspondence, mainly official, contracts, accounts, miscellaneous memoranda and the like, all written in that Sanskrit language and Kharoṣṭhī script which during the first centuries before and after Christ were used on the Indian north-west frontier and in the adjacent portions of Afghanisthan.'[15] At Endere similar documents turned up in refuse heaps. Kharoṣṭhī inscriptions discovered at Miran and written in black ink appearing surprisingly fresh even after the lapse of almost two thousand years bear close resemblance to those found at Niya.

The language used in all these documents is an early form of Indian Prakrit, the Gāndhārī Prakrit. This Prakrit is rich in loan words from Iranian, Sogdian, Greek, and Tibetan languages. For phonetic reasons some of the letters became encumbered with special signs. The Gāndhārī Prakrit developed its own literature which included *inter alia* a recension of *Dhammapada*, *Pratītya-samutpāda*, and a large number of Buddhist canonical texts produced by an international team of Buddhists comprising Sogdians, Indians, Parthians, and Yueh-chihs. All these documents are in keeping with a local tradition recorded by Hiuen Tsang that in the second and third centuries B.C. Khotan was colonized by immigrants from Takṣaśilā.

Sanskrit and Brāhmī: Scholars are generally agreed that the Brāhmī script, like the Kharoṣṭhī, was derived from some early form of Semitic alphabet. Weber thought it to be the most ancient Phoenician North Semitic alphabet; Taylor considered it to be a lost South-Arabian alphabet, the predecessor of the Sabaean; while according to Deecke, the parents were the Assyrian cuneiform characters through some ancient South Semitic ones. Summarizing the modern views, Diringer picks up early Aramic alphabet as the prototype of the Brāhmī and says: 'The acknowledged resemblance of the Brahmi signs to the Phoenician letters also applies to the early Aramic letters, while in my opinion there can be no doubt that of all the Semites the Aramaean traders were the first who came in direct communication with the Indo-Aryan merchants.'[16]

The Brāhmī script as the vehicle of the Sanskrit language spread throughout the length and breadth of India and followed the language to Central Asia, Tibet, Mangolia, and elsewhere. Brāhmī inscriptions on didactic matters and deeds of gifts have been found in Kara Tepe in Afghanistan and in Dilverdzhina in northern Afghanistan. Merv, in Soviet Central Asia, has yield-

[15] Aurel Stein, *On Ancient Central Asian Tracts* (Macmillan and Co., London, 1933), p. 28.
[16] D. Diringer, *The Alphabet* (Hutchinson, 1947).

ed the Vinaya text of the Sarvāstivāda school—nearly 200 leaves in Brāhmī and dated about the fifth century A.D. In the Tarim basin the adoption of the Brāhmī script followed the growing popularity of Sanskrit there. The script was also adopted for writing Tokharian B, the language of Kucha, Tokharian A, the language of Karashar or Agnideśa, and Śaka-Khotanese.[17] Sanskrit manuscripts in Brāhmī, written on birch bark, palm leaves, leather, and paper have been excavated from a number of sites in the Tarim basin—Kucha, Tumshuq, Shorchuq, Turfan, Tung-huang, Khotan, and Kashgarh. Hiuen Tsang noticed the use of the Brāhmī script in Karashar, Kucha, Kashgarh, Khotan, and Yarkand and observed that the script had been taken from India and modified as necessary in different places, indicating that by the seventh century A.D. the script had attained considerable popularity in Central Asia.

The language and the script were employed largely for the compilation of canonical texts by the Sarvāstivāda school of Hīnayāna Buddhism. Non-canonical texts were not also wanting as is evident from manuscript fragments of three Sanskrit dramas from Kucha, Aśvaghoṣa's *Buddhacarita* and *Saundara-nanda-kāvya* from Shorchuq, a number of medical texts, e.g. *Nāvanītaka*, *Yoga-śataka*, *Siddhasāra*, and *Jīvapustaka*, and astrological and astronomical fragments. These canonical and non-canonical Sanskrit texts, coming as they do from a wide region, point unmistakably to the popularity of Buddhism in particular and of Indian culture and science in general. The Central Asian scholars were so enthusiastic that they did not remain satisfied with the original works of the masters, but produced new Sanskrit works as well as translations and commentaries in their own local languages. The Khotanese translations of *Vajracchedikā*, *Aparimitāyuḥ-sūtra*, and *Suvarṇa-prabhāsa-sūtra*, and medical and technical texts are instances in point. Versatile Kumārajīva of Kucha was a prolific translator. The same thing happened in other tongues—Sogdian, Tokharian, and Uighur-Turkish. Sogdian, the language of the Oxus valley, became enriched by contact with Sanskrit.

To sum up, Indian merchants, missionaries, and colonizers not only introduced Buddhism as an all-embracing faith in Central Asia, but also brought about a linguistic and literary revolution through their transmission of Gāndhārī Prakrit and Sanskrit and their vehicles, Kharoṣṭhī and Brāhmī. While this process helped the regional languages to develop and acquire new strength, Sanskrit itself became the universal language of culture over a vast tract.

INDIAN MEDICINE ABROAD

Greek Knowledge of Indian Medicine: A large number of plants of remarkable medicinal properties together with a considerable amount of Indian medical knowledge must have travelled to West Asia and the Aegian world during

[17] Mukherjee, *op. cit.*, p. 705.

the fifth century B.C. The Hippocratic corpus (fifth century B.C.) mentions pepper and it's medicinal properties. Elgood records that Alexander the Great was conversant with the Indian skill in the use of poison in warfare and possibly learnt from Indian doctors some antidotes for the viper's venom.[18] It is well known that war casualties in the Macedonian army were much smaller in Persia than in India probably on account of the use by the Indian defenders of poisoned spears and arrow-heads. Ptolemy, the Greek general under Alexander, narrowly escaped death from wound by a poisoned spear. During his Indian campaign Alexander himself was lucky not to have succumbed to a spear thrust because the latter was not poisoned, but suffered from a chronic fistula leading from the chest wall to the lung. Aristotle, who knew enough of Indian medicine, the skill of Indian physicians, and the proverbial 'poison maiden', cautioned his pupil against accepting gifts during his Indian campaign, as we now know it from his letters to Alexander which have come down to us in Arabic translations by al-Baṭrīq and later on in Latin translations. In one such letter he wrote (quoted by Elgood):[19]

> Remember what happened when the King of India sent thee rich gifts, and among them that beautiful maiden whom they had fed on poison until she was of the nature of a snake. Had I not perceived it because of my fear, for I feared the clever men of those countries and their craft and had I not found by proof that she would be killing thee by her embrace and by her perspiration, she would surely have killed thee.

Roman writers and encyclopaedists such as Celsus, Scribonius Largus, Pliny, and Dioscorides made several references to Indian medicine and herbals. Celsus made frequent references to Indian plant product in his drug prescriptions and gave an excellent description of Indian lithotomy, the surgical operation successfully developed and practised by the ancient Hindus. In Galen's voluminous works one comes across references to an Indian ointment for the eyes, called 'Indian basilicon', and to an Indian plaster, of which prescriptions were provided by a surgeon with a Greek name (Tharseos of Thrasos).

Pneumatic Theories—Greek and Indian: Apart from such stray and superficial references to Indian remedies and practices there are interesting parallelisms in medical theories in the two systems. We refer to the Āyurvedic theory of *vāta* and the Greek pneumatic theory as found in a Hippocratic tract and in Plato's *Timaeos*, of which a comparative study has been made by Filliozat.[20] The Āyurvedic theory is met with in the *Bhela-saṁhitā*, *Caraka-saṁhitā*, and *Suśruta-saṁhitā*, but the concept dates back to Ṛg-Vedic times. The early

[18]Cyril Elgood, *A Medical History of Persia and the Eastern Caliphate from the Earliest Times until the Year A.D.* 1932 (Cambridge University Press, 1951), pp. 29-30.

[19]S. N. Sen, 'Influence of Indian Science on other Culture Areas', *Indian Journal of History of Science*, V, No. 2 (1970), p. 334.

[20]J. Filliozat, *La Doctrine classique de la Médicine indienne* (Paris, 1949). See also his article '*L'Inde et les échanges scientifiques dans l'antiquité*', *Journal of World History*, I, No. 1 (1953), pp. 353-67.

Saṁhitās doubtless contain the idea of breath or *prāṇa* regulating all physiological activities within the body in the same manner as air controls the movement of the physical world outside. Thus, air (*vāta*) 'the lord of the universe' (*viśvasya bhuvanasya rājā*); 'the first-born to participate in the (universal) order' (*prathamajā ṛtāvā*), and 'the soul of the gods, the germ of the universe' (*ātmā devānāṁ bhuvanasya garbhaḥ*).[21] The *Atharva-Veda* identified air with breath (*prāṇa*) or the vital spirit moving the human body as follows: 'It is said that breath (*prāṇa*) is *mātariśvan*; it is air which is called breath. (Everything) existed and exists in the breath and it is in the breath that everything is established (*Prāṇamāhurmātariśvānaṁ vāto ha prāṇa ucyate; prāṇe ha bhūtaṁ bhavyaṁ ca prāṇe sarvaṁ pratiṣṭhitam*).'[22] Important as these statements are, the physiology of breath as we find elaborated in Āyurvedic texts was a development of a later period. Yet the differentiation of *prāṇa* into several categories (*prāṇa, apāna, vyāna, samāna, udāna*), each being endowed with special functions, was probably achieved in the Vedic period. Likewise, the *tridoṣa* theory admitting the integrated roles of bile (*pitta*) and phlegm (*kapha*) along with those of *vāta*, had its origin in the same period long before their systematization in medical compendia.[23]

A similar *vāta* or pneumatic physiology is met with in a Hippocratic work called *On Winds* (περιφυσων) which presents a treatment of the subject more or less agreeing with the teachings of the *Suśruta-saṁhitā*. In the Greek text, air is considered both as the great universal agent and the vital spirit responsible for many maladies, epidemic diseases, and multifarious actions in the animal body. Unlike the *vāta* of the Āyurveda, the pneuma of the Greek medical text is not associated with the activities of bile and phlegm. A similar pneumatic theory appears in Plato's *Timaeos*. Here a distinction is made between a group of diseases caused by pneuma, bile, and phlegm and another group brought about by the derangement of the four bodily elements: earth, fire, water, and air. Various bodily troubles are attributed to air as are done in the Indian texts, and the idea that these sufferings and convulsions are provoked by that air which is retained in the body is the same in the *Timaeos* and Āyurvedic works.

Timaeos was produced when Plato (d. 347 B.C.) was advanced in age. The Hippocratic tract, *On Winds*, must be dated before Aristotle (384-322 B.C.). So both these works can be safely placed in the fourth century B.C. In India, however, the physiological role of *vāta* was recognized during the period of the development of the Brāhmaṇa literature which has been dated

[21] *R. V.*, X. 168. 2-4.

[22] *A. V.*, XI. 4. 15.

[23] The nature and action of breath in the human body are detailed in the *Caraka-saṁhitā*, I. 12; *Bhela-saṁhitā*, *Sūtrasthāna*, 16; and *Suśruta-saṁhitā*, II. 1.

around 800 B.C. according to conservative estimates. But the concept is older still, being traceable to the time of the Vedic Saṁhitās. The anteriority of the Indian *vāta* theory being thus clearly established, it is tempting to say that the Greek pneumatic theory might have been borrowed from India. Here we must admit that the notion of 'vital air' circulating through living bodies was a commonplace idea in antiquity. It is recorded in Ebers Papyras in ancient Egypt, and the *Avesta* and other sacred literature of Persia make certain references to the theory. With regard to India, where the idea is also very ancient, the important point to note is that here we notice a gradual development of the idea of *prāṇa* (breath) as the controlling agent of the living body. There is no such evidence of a gradual development of the Greek pneumatic theory which to all intents and purposes appears rather out of context with the general physiological ideas of the Greek medical schools. If borrowing should be the case, one can always argue in favour of a nearer neighbour—either Egypt or Persia. But then there is evidence of Indian prescriptions and remedies passing into the Hippocratic collections, e.g. the use of pepper in treatises like *The Diseases of Women* and *On the Nature of the Female.* When it is remembered that the period between the fifth and fourth centuries B.C. was one of intense doctrinal activity in both India and the Greek world, and that the same period also witnessed great political and military activity leading to the emergence of Persia as a bridge between India and the Greek colonies in Asia Minor and Ionia, the transmission of this highly attractive *vāta* theory from India to Ionia does not appear at all improbable.

Medical Texts in Central Asia: Doubts and uncertainties which naturally surround ancient Indo-Greek relations in the field of science and culture do not exist in the case of Indo-Central Asian relations in view of datable manuscripts having been found from the depths of sand. As we have already mentioned, non-canonical works unearthed in Central Asia include a number of medical texts based on Indian teachings. The most important of them is the Bower Manuscript,[24] after Major General L. H. Bower who obtained it from a man in Kucha, the latter having discovered it while digging for treasures. Also known as *Nāvanītaka* (cream), the manuscript deals mainly with medical remedies and prescriptions and was probably compiled between the fourth and sixth centuries A.D. Hoernlé divided the Bower Manuscript in seven parts, while Visvanadha Sarma preferred to divide the work into three books: *Nāvanītaka*, *Praśnaśāstra*, *Mahāmāyūrī-vidyā*.[25] Nothing is known about the author except a few guesses. 'Nāvanītaka' could be the name of the author; *Mahāmāyūrī-vidyā* could be the work of a Buddhist. Ancient medical teachers

[24]Ed. A. R. R. Hoernlé (Calcutta, 1893-1912).

[25]Visvanadha Sarma, 'Nāvanītakam', *Indian Journal of History of Medicine*, Vol. V, No. 2 (1960), pp. 5-9.

like Ātreya, Suśruta, Punarvasu, Kāśyapa, Garga, Vaśiṣṭha, Karala, and Suprabha are mentioned, and the style of writing agrees with that followed by Indian authors generally. The medical remedies and their prescriptions elaborated in the various chapters include (i) powders and their formulations; (ii) medicinal ghee (*ghṛta*); (iii) medicinal oils (*taila*); (iv) mixtures for different diseases; (v) formulas for enema; (vi) elixirs (*rasāyana-vidhi*); (vii) *maṇḍa*, *peya*, and other liquid preparations; (viii) aphrodisiacs (*vṛṣya-yogas*); (ix) eye ointments; (x) hair dyes; (xi) preparations of *śilājit*, *citrakalpa*, *abhaya*, etc.; (xii) mixtures for children's diseases; and (xiii) female diseases and sterility. The uses and applications of myrobalans have received prominent treatment; likewise, the uses of catheter, eye and skin diseases and their treatments, medicinal properties of *laśuna* (garlic), and recipes for hair dyes are detailed in the work.

Pelliot found in the same Kucha region a few folios of another medical manuscript in Sanskrit with a translation in Kuchean. This is the well-known *Yogaśataka* available in Tibetan translations in Nepal, Ceylon, and various parts of India. The work is a summary in one hundred formulas of the eight-limbed (*aṣṭāṅga*) Āyurvedic system of medicine. The manuscript was compiled in the seventh century A.D. and is attributed to Nāgārjuna, the redactor of *Suśruta-saṁhitā*.[26]

Special mention should be made of a Khotanese medical text of which the India office Library possesses an excellent manuscript. H. W. Bailey published a facsimile copy, the *Codices Khotanenses*, and Sten Konow produced an English translation along with the text.[27] The work is bilingual, written in Sanskrit and Khotanese, the former being in a very corrupt form. It resembles the Bower Manuscript in being primarily a handbook of medical prescriptions. The text lays stress on the efficacy of *mantras* for the preparation and administration of certain types of drugs intended for treatment of poisons, of which an example may be cited as follows: The *agada* 'drugs should be given, well measured in portion, by the doctor; all these drugs together with water; which are the most efficacious, hear what I tell you, Jīvaka, wherewith those drugs and that *agada* should be consecrated; thus: kisi, kisi, kisalambi, hili, hili, obeisance to the Buddha, may the *mantrapada* succeed, *svāhā*. The doctor who now prepares this *agada* —this *mantra* should now continually be spoken so; . . . .' There are several preparations with indications of diseases for which these should be used, e.g. *aśvagandhā* for cough, respiratory troubles, consumption etc.; *kalyāṇaka* for insomnia, fever, *arśa*, *unmāda*, *hikkā*, etc.; *balagarbha* for wrinkles, white hair,

[26] L. Renou and Filliozat, *L'Inde classique* (*École Française d'Extrême-Orient*, Hanoi, 1953), p. 157.

[27] Sten Konow, *A Medical Text in Khotanese* (CH. 11003 of the India Office Library)—with Translation and Vocabulary (Oslo, 1941).

insomnia in women, *raktapitta*, consumption, derangement of blood, etc., to cite a few cases.

The examples, names of drugs and diseases, methods of preparation, the various ingredients of herbal, animal, and mineral origin, the chanting of *mantras* all are typically Indian. These show that the whole system and tradition were adopted by the local people and incorporated in their language to facilitate the work of native doctors and patients.

Indian Medicine in China: By the seventh century A.D. fragments of Indian chemistry, medicine, and pharmacology must have travelled to China through overland silk routes or along sea-lanes. In the accounts of Wang Hsuan-Tshe (*c*. 648), ambassador to the court of Magadha at the time of Harṣa, we read of an Indian scholar reporting to the emperor of China about his ability to make people live for two hundred years with the use of extraordinary drugs. This scholar also informed the emperor that the learned men of India produced from minerals in the mountains a kind of liquid substance called *pan-chha-cho shui* ('pan-chha-cho', water), which was capable of dissolving herbs, wood, metals, and iron. The potent liquid was probably a mineral acid whose preparation was kept as a closely guarded secret. During the time of Wang Hsuan-Tshe, a Chinese monk of the name of Hsuan-Chhao spent some years in India in studying Sanskrit and was asked by the Chinese emperor to send to China some expert Indian physicians and alchemists presumably for making the elixir of life. We do not have further details of Hsuan-Chhao's efforts, but it is certain that some Indian alchemists and physicians did go to China and engage themselves there in alchemical and medical preparations recorded in *Thung Chien Kang Mu*.[28] The work mentions the name of So-Po-Mei or Lu-Chia-I-To, probably an Indian name transliterated into Chinese. In the seventh and the following centuries Indian alchemy, medicine, and medicinal plants did generate some interest of which one important harvest was the passage into the Chinese pharmacopoeia of the Indian chaulmoogra oil under the Chinese name *ta-feng-tzu*.

Indian Medicine in Arab Culture Area: The rise of Islam in West Asia witnessed a revival of interest in Indian intellectual efforts generally and scientific advancement in particular. The historiography of this area and the period is in a much better shape, but is rendered complicated by the impact of a number of cultures, the Babylonian, the Sassanian, the Greek, and the Indian. In the Sassanian period Indian literature had already had its impact on its Persian counterpart. Thus the fables of *Pañcatantra* had been translated into Pahlavi, which inspired al-Muquaffa to render them into Arabic under the title *Kalīla wa Dimna*. Likewise, the Arabs first came to know of the *Caraka-saṁhitā* through

[28] Needham, *op. cit.*, p. 212.

a Persian translation of it and later on produced an Arabic version, as we have it from the *Fihrist.* The ministerial families of Barmak who had migrated from Balkh and risen to positions of power under the Abbāsids were admirers of Indian medicine. It was largely due to the patronage of Barmak ministers that Indian physicians like Dhanya or Dhanin, Kaṅka, Vyāsa or Bādarāyaṇa were appointed in Bagdad hospitals and engaged for translating Sanskrit medical, pharmacological, and toxicological texts into Arabic.[29] We know from D'Herbelot's *Bibliography* that a tract on poisons, the works of Suśruta and Vāgbhaṭa, and a number of other medical books were translated into Arabic. Al-Rāzī utilized these translations in his famous medical encyclopaedia *Kitāb al-hāwī* (*Continens*).

ASTRONOMY AND MATHEMATICS

Another fertile field for the exchange of ideas and methods was astronomy and mathematics. Both these related subjects interacted with each other and had a social origin. In India the development of an elaborate system of rituals as an integral part of religious practices called for accurate time-reckoning and a dependable calendar, and therefore required astronomical studies. Rudiments of these studies are well recorded in the Vedic Saṁhitās, as for example, the periodic motions of the sun and the moon, the moon's sidereal and synodic periods, the lengths of the month and the year, the eclipses, the path of the sun and the moon in the starry heavens marked by a fixed stellar zodiac, and the solstices. These elements were intelligently integrated to work out a calendar to enable the performance of various sacrificial rites on the new and full moon days, the equinoxes, and the solstices, and if possible, on the great occasions of lunar and solar eclipses. The whole exercise involved painstaking observations day after day and night after night as well as many calculations. It is no wonder that the *nakṣatra-darśa* and the *gaṇaka*, by which terms the skilled astronomers were meant, commanded and enjoyed the greatest respect in the priesthood and in society as the entire religious and civil life depended upon their calculations and directions. This situation was not peculiar to India only. Other ancient societies built on the Tigris-Euphrates, the Nile, and the Yellow river in the Old World and the architects of the Mayan civilization in the New were confronted with similar problems and found indentical solutions with various degrees of refinement and sophistication. This refinement often assumed considerable importance as far as it concerns accurate time-reckoning and calendar-making, and we notice on the part of every ancient civilization in contact with each other an unmistakable interest in the astronomical labours and innovations of others.

[29]E. C. Sachau, *Alberuni's India*, I (1910).

Stellar Zodiac: A good instance in point is the development of the system of stellar zodiac or lunar mansions as the reference frame for the study of motions of planetary bodies. The Babylonians, Chinese, Arabs, and Hindus all developed this system, with large and small variations, at fairly early dates (except the Arabs), generating some controversy as to the anteriority of discovery of the system. The Sinologists, Indologists, and Assyriologists have laid powerful claims on the anteriority as well as originality of their respective systems to which we shall now briefly refer.

The claim for the Indian *nakṣatra* system is based on the following: The system is known to the *Ṛg-Veda* where the term *nakṣatra* has been used in both the sense of stars and that of lunar mansions. In the latter sense, at least two *nakṣatras* are mentioned, namely, Maghā (Aghā) and Phālgunī (Arjunī). Although other *nakṣatras* are not specifically mentioned, Ludwig, Zimmer, and others hold that twenty-seven *nakṣatras* were included in the number thirty-four (the sun, moon, five planets, and twenty-seven *nakṣatras*) mentioned in the *Ṛg-Veda*. The full list of twenty-seven or twenty-eight *nakṣatras* headed by Kṛttikā appears in the Saṁhitās of the various schools of the *Kṛṣṇa Yajur-Veda* as well as in the *Atharva-Veda*. *Nakṣatra* Abhijit is not included in all the lists, making the total vary between twenty-seven and twenty-eight. The names of *nakṣatras*, after their formulation in the time of the Vedic Saṁhitās, have remained more or less unchanged.

Originally, the term *nakṣatra* possibly meant asterism, stars, or star groups. Subsequently, it meant one of twenty-seven equal divisions of the ecliptic, that is to say, an ecliptic space of 13°20′; each such space was marked by a determinant star (*yogatārā*). In the *Vedāṅga-jyotiṣa* the position of the vernal equinox has been given as 10° from the beginning of the *nakṣatra* Bharaṇī. In later astronomical works a *nakṣatra* division of 13°20′ or 800′ has been clearly defined and positions of determinant stars are given in degrees and minutes with respect to the starting-point of the *nakṣatra* concerned. Thus in India the *nakṣatra* system has been used in the sense of a stellar zodiac from the time of the *Vedāṅga-jyotiṣa* (*c.* 600 B.C.), if not earlier.

The Chinese lunar mansions are called *hsius*. Two *hsius* stars, e.g. the Bird Star (α Hydrae) and Fire Star (π Scorpii or σ Scorpii) have been found inscribed in oracle bones belonging to the Shang period (*c.* 1500 B.C.). By the eighth or ninth century B.C. about eight *hsius* are recognized and mentioned in the *Book of Odes* (*Shih Ching*). No further change in the list comes to notice until the third century B.C., when the *Monthly Ordnances* (*Yüeh Ling*) clearly mentions a list of twenty-three *hsius* with the exception of *Chi*, *Shih*, *Mao*, *Shen*, and *Hsing*. As some of the missing *hsius* are found in earlier records it cannot possibly be doubted that the full list of *hsius* was known during the time of *Yüeh Ling* (third century B.C.). One, however, meets with the full list of twenty-

eight *hsius* only in *Huai Nan Tzu*, composed by Liu-an around 160 or 150 B.C.[30] Moreover, the *hsius* were originally selected to mark the equator for facilitating observation of the culmination of stars and not to delineate the ecliptic. These were used in the sense of lunar zodiac from the time of *Huai Nan Tzu*. Thus, although the *hsius* go back to the second millennium B.C., they were first used as an equatorial system and subsequently as a lunar zodiac in the period of the warring states (403-247 B.C.). There are other important differences between the *nakṣatras* and the *hsius* and between their determinant stars. In the case of India, the full list of *nakṣatras* appeared in the recensions of the *Kṛṣṇa Yajur-Veda*. If, with Winternitz, we agree to a period between 2500 B.C. and 2000 B.C. as the beginning of the development of Vedic literature, the Ṛg-Vedic reference to Maghā, Phālgunī, and possibly a few others leave no doubt as to the earlier career of the *nakṣatra* system in India. Moreover, from the very beginning of their concept, the *nakṣatras* were associated with the ecliptic, appeared as a system of lunar zodiac, and maintained their character, through the Brāhmaṇas and the Sūtras, up to the time of the Siddhāntas, when the stellar zodiac of twenty-seven divisions was replaced by the more convenient zodiac of twelve signs and their sexagesimal subdivisions.

Towards the end of the second millennium B.C. the Babylonians had developed a good knowledge of constellations and applied it in following the motions of the sun, moon, and planets.[31] They had divided the sky into three zones of twelve sectors each, these sections containing the names of constellations, planets, and simple numbers in arithmetical progression. Moreover, three stars or constellations were assigned to each month, clearly showing an attempt to obtain some kind of correlation of months to constellations. The Babylonian cuneiform texts contain a series known as mulAPIN texts dated about 700 B.C. Constructed on the basis of older materials, the texts give names of about eighteen constellations more or less along the ecliptic. In later texts the number of stars and constellations was either increased or diminished—the maximum number registering thirty-three or thirty-six with a view to determining more accurately the positions of planets. Fritz Hommel first tried to construct out of thirty-three or thirty-six such Babylonian stars a lunar zodiac comprising twenty-four ecliptic stars.[32] On comparing the Babylonian ecliptic stars with the Arabian *manāzils*, Hommel found agreement in the case of sixteen lunar mansions and concluded that the *manāzils* were derived from Babylonian sources. Hommel pushed this agreement further and put forward

[30]Co Ching Chu, 'The Origin of Twenty-eight Lunar Mansions', *Acts du VIII[e] Congrès International d'Histoire des Sciences*, Vol. I (1956), pp. 364-72.

[31]S. N. Sen, 'Astronomy', *A Concise History of Science in India*, ed. D. M. Bose, S. N. Sen, and B. V. Subbarayappa (1971), pp. 71-72.

[32]Fritz Hommel, '*Über d-Ursprung u.d. Alter d. arabischen Sternnamen u. insbesondere d. Mondstationen*', *Zeitschrift der Deutschen Morgenländischen Gesellschaft*, Vol. XLV (1891), pp. 592-619.

the theory of common origin in accordance with which the plan, first worked out in Babylon, led to other lunar zodiac schemes, e.g. the Indian *nakṣatras* and the Chinese *hsius*. With regard to the Babylonian influence upon the Indian *nakṣatras*, Thibaut pointed out that there was some agreement with regard to only one-third of the total number, and that seven *nakṣatras* (Mṛgaśirṣa, Ārdrā, Aśleṣā, Hasta, Mūla, Abhijit, and Śraviṣṭhā) differed widely from their opposite numbers in the Babylonian series. Moreover, agreement should not be surprising and suggestive of borrowing inasumch as, in any independent attempt at selection of conspicuous stars along and near the ecliptic, the brightest stars should be picked up, and such stars are α Tauri, β Geminorum, α Leonis, α Virginis, α Scorpionis, all of first or near first magnitude. Another weakness of the theory is that the Babylonian series comprises thirty-three or thirty-six stars whereas the *manāzils* number twenty-eight and the *nakṣatras* twenty-seven or twenty-eight.

Despite Hommel, Arabian *manāzils* agree more closely with the *nakṣatras*. The first or the leading *manāzil* is ash-Sharaṭān corresponding to *nakṣatra* Aśvinī which about the fifth or sixth century A.D. found itself at the point of intersection of the equator and the ecliptic, and also at the head of the *nakṣatra* list. Nineteen *manāzils* agree closely with their corresponding *nakṣatras*, and the disagreement is limited to only seven *nakṣatras* (Ārdrā, Hasta, Svātī, Abhijit, Śroṇā, Śraviṣṭhā, and Revatī). These coincidences and the recorded evidence of transmission of Indian astronomical texts led Weber to believe at one time that Arabian *manāzils* had been derived directly from Indian *nakṣatras*. Filliozat has, however, warned that close resemblance should not be taken as an *ipso facto* proof of Arab borrowing from India.[38] The *manāzils* are mentioned in the Qu'rān (X. 5; XXXVI. 39). According to Weber's interpretation, the Hebrew word 'mazzaloth' or 'mazzaroth' occurring in the *Book of Job* (38.32) and the *Book of Kings* (23.5) stands for *manāzil*, suggesting its Semitic origin. Finally, there was the question of Iranian influence as argued by Leopold de Saussure who drew attention to the list of twenty-eight lunar mansions recorded in the *Bundahishn* (II.3). Attempts have been made to trace the system in the *Avesta* (*Yasna*, XVI. 3-6), but the number of lunar mansions given there is thirty. The *Bundahishn* again is a production of a later period when Indo-Iranian contacts were close.

If the Indian *nakṣatras* and lunar mansions of Babylon, China, Iran, and Arabia eluded all attempts at discovering a common origin and a central diffusion point, we are on firmer grounds regarding the appearance of lunar mansions in the literary documents of Tibet and Central Asia. Here the Indian influence is unmistakable. These documents concern periods in the first

[38] J. Filliozat, '*L'Inde et les echangés scientifiques dans l'antiquité*', *Journal of World History*, Vol. I (1953), pp. 353-67.

millennium of the Christian era when Buddhist missionaries from India and local scholars were actively engaged in translating Indian works and propagating Indian thought and culture. The Tibetan Tripiṭaka, for example, contains a textbook called *Akṣaṇimitta Kṛtinirdeśa* (omina) by one Garga, which in chapter 16 gives a list of twenty-eight Indian *nakṣatras* headed by Kṛttikā. The 'Turfan Fragments' unearthed from the oasis of Turfan contain lists of lunar mansions in Uighur, which were studied by Rachmati and Winfried Petri.[34] The first fragmentary list mentions twenty *nakṣatras* after their Sanskrit names in simplified spelling. The missing *nakṣatras* are Aśvinī at the beginning and six others —Śravaṇa, Dhaniṣṭhā, Śatabhiṣaj, Pūrvabhādrapada, Uttarabhādrapada, and Revatī, at the end. From the proportionality 4 : 9 equalling 12 : 27 it appears that the ecliptic circle containing twelve zodiacal signs is divided into twenty-seven *nakṣatras*, Abhijit being omitted. The *nakṣatras* are accompanied by geometrical sketches such as equilateral triangles, squares, and rectangular broken lines representing, as per Petri's interpretation, the number of stars associated with each *nakṣatra*. Rachmati's second list gives twenty-eight *nakṣatras*, from which some examples of Uighur transliteration of Sanskrit *nakṣatra* names are given as follows: Kṛttikā —Kirtik; Mṛgaśīrṣa — Mrgasir; Ārdrā —Ardir; Punarvasu —Punarbasu; Puṣyā —Pus; Aśleṣā — Aslis; Pūrvaphālgunī— Purbapalguni; Hasta —Xast; Citrā —Caitir; Svātī— Suvadi; Anurādhā — Anurat; Mūla —Mul; Pūrvāṣāḍhā —Purvasat; Uttarāṣāḍhā — Utrasat; Śravaṇa —Sirivan; Dhaniṣṭhā —Danis; Revatī —Rivadi; Aśvinī —Asvini. There is excellent agreement among Tibetan, Uighur, and Indian *nakṣatra* lists, which does not, however, exclude some obvious influence from the Arabian *manāzils*.

Greek and Babylonian Influence on Indian Astronomy: Greek and Babylonian influence upon the development of astronomical Siddhāntas has been known for a long time. Garga and Varāhamihira have referred to the proficiencies of the Yavanas (Greeks) in astronomy and stated that they should be honoured as *ṛṣis* (sages) although they are *mlecchas* (foreigners). Varāhamihira, in his astrological work *Bṛhajjātaka*, freely used many Greek technical terms applied in astronomical and astrological works. The names of the twelve signs of the zodiac were transliterated into Sanskrit as follows: Kriya —Meṣa; Tāvuri — Vṛṣa; Jituma —Mithuna; Leya —Siṁha; Kulīra —Karkaṭa; Pāthona — Kanyā; Jūka —Tulā; Kaurpya —Vṛścika; Taukṣika —Dhanu; Ākokera — Makara; Hṛdroga —Kumbha; and Ittha —Mīna. Similarly, Greek words *kendra* for anomaly, *āpoklima* for inclination, *liptā* for minutes, *horā* for hour, and a few others passed unchanged into Sanskrit. Of the five Siddhāntas summarized by Varāhamihira in his *Pañcasiddhāntikā*, the *Romaka-* and

[34] Winfried Petri, 'Uigur and Tibetan Lists of the Indian Lunar Mansions', *Indian Journal of History of Science*, Vol. I, No. 2 (1966), pp. 83-90.

Pauliśa-siddhānta, as their very names indicate, were long taken to contain elements of Graeco-Alexandrian astronomy in spite of their Indianization. The *Romaka* used the Metonic cycle, and the *Pauliśa* used a period different from the *yuga* of later Hindu astronomers. One of them computes *ahargaṇa* (number of civil days that elapsed from the beginning of an epoch) for the meridian of Yavanapura and gives the longitude difference between Yavanapura and Ujjayinī. Noticing these elements Thibaut observed that 'the Pauliśa and Romaka-siddhāntas were the earliest Sanskrit works in which the new knowledge imported from the West was embodied'.[35] Pingree, from his study of an astrological text, the *Yavana Jātaka* of Sphujidhvaja, has endeavoured to show Graeco-Alexandrian influence on Indian astronomical-cum-astrological labours in the first few centuries of the Christian era when the Khaharātas, a branch of the Śakas, were politically prominent in western India with their capital at Ujjayinī and trading posts at Minnagara and other places with intimate maritime connections with Alexandria.[36] The epicyclic, eccentric-epicyclic, and eccentric-eccentric geometrical models were also introduced into Indian astronomical Siddhāntas from Greek sources, although the exact channels of transmission are not very clear. Sengupta was of opinion that Āryabhaṭa's epicyclic planetary astronomy was possibly derived from Babylonian sources and particularly mentioned Pradyumna and Vijayanandin who made a special study of superior and inferior planets.[37] Van der Waerden is inclined to believe that the transmission of the epicyclic ideas with the application of sinusoidal relationship probably took place between the time of Hipparchus and that of Ptolemy.

The *Vāśiṣṭha-siddhānta* summarized by Varāha is an important text giving evidence of borrowing from Babylonian sources. The text yields the value of the anomalistic months as 27; 33, 16, 22 ... in sexagesimal unit in close agreement with the Babylonian convergents 248/9 and 3031/110 discovered in a tablet from Uruk and discussed by Schnabel. Other planetary data given in the *Vāśiṣṭha-siddhānta* are also based on Babylonian sources, as have recently been clarified by Neugebauer and Pingree in their recent edition and study of the *Pañca-siddhāntikā*.[38]

Sino-Indian Interaction: There is abundant literature on Sino-Indian intercourse as far as it concerns the spread of Buddhism into China. From the time of Dharmarakṣa (third-fourth century A.D.) and Kumārajīva (fourth-fifth

[35] *Pañcasiddhāntikā of Varāhamihira*, ed. G. Thibaut and S. Dvivedi (Benares, 1889; reprint: Motilal Banarsidass, 1933).

[36] David Pingree, 'A Greek Linear Planetary Text in India', *Journal of the American Oriental Society*, Vol. LXXIX (1959), pp. 282-84.

[37] P. C. Sengupta, 'Āryabhaṭa, the Father of Indian Epicyclic Astronomy', *Journal of the Department of Letters*, XVIII (Calcutta University, 1928), p. 56.

[38] O. Neugebauer and Pingree, *Pañcasiddhāntikā*, with text, translation, and commentary.

century A.D.) a long line of Buddhist scholars from Kashmir, and from western, central, and eastern India (from Nālandā in particular) visited China by land and by sea, spent many years there in preaching Buddhist doctrines and translating canonical texts. Some of them were no doubt engaged in the dissemination of secular learning such as astronomy, mathematics, medicine, etc. The catalogue of the Sui dynasty, compiled in A.D. 610 by Wei Cheng, records a number of Brahminical works on astronomy and mathematics as follows:

(1) *Po-lo-mên t'ien-wen-ching*—Brahminical astronomy, in twenty-one books;
(2) *Po-lo-mên chieh-chieh hsien-jen t'ien-wen-shu*—Astronomical dissertations of the Brahmin sage Chieh, in thirty books;
(3) *Po-lo-mên t'ien-wen*—Brahminical astronomy, in one book;
(4) *Po-lo-mên Suan-fa*—Brahminical methods of calculation, in three books;
(5) *Po-lo-mên yin yang suan ching*—Brahminical method of calculating time, in one book; and
(6) *Po-lo-mên suan ching*—treatise on Brahminical mathematics, in three books.

Nothing is known of these works beyond their titles and also of the extent to which these stimulated astronomical and mathematical studies there. Yabuuti mentions that during the first few centuries of the Christian era a number of Buddhist scriptures with Indian astronomical contents were translated into Chinese; the most important of them were the *Mātaṅga-avadāna* and the *Hsiuyao-Ching*.[39] Again, we do not know about the contents of these works and can only surmise that these early tracts discussed in all probability Indian astronomy prior to the appearance of the Siddhāntas.

The Thang period (seventh-eighth century A.D.) witnessed considerable activity of a number of Indian astronomers in China. In the preceding century a small astronomical school or board was founded at Chang-Nan. This school propagated the study of Indian astronomy represented by Kāśyapa, Gautama, and Kumāra. Records of the Thang dynasty mention four astronomers all bearing the name Ch'u-t'an meaning Gautama. Ch'u-t'an Chuan (fl. 618) composed a calendar for the first Thang emperor; Ch'u-t'an Lo, president of the board mentioned above, composed another calendar called *Kuang-chai*. The most well known of the Gautama school was Ch'u-t'an Hsi-ta who prepared the *Chiu-Chih-li* (Chinese translation of *navagraha*) calendar on the basis of Indian Siddhāntas. The text deals with a number of Indian mathematical rules as applicable to astronomy and contains one section on Indian numerals

[39]Kiyosi Yabuuti, 'Indian and Arabian Astronomy in China'. *Silver Jubilee Volume of the Zinbun-Ka aku-Kenkyusyo* (Kyoto University, 1954).

and another on sine tables. Yabuuti who has studied this calendar observes at one place: 'In the surviving block-print text, the numerals themselves are no longer in evidence. But the text does say that there are nine of them from which all numbers can be formed.' It also states that empty spaces are indicated by a dot which, it is needless to say, fulfilled the same function as zero. From this simple statement it is evident that Indian numerals made their way to China in the early eighth century. Sarton also observes: 'The Chinese treatises of Ch'u-t'an Hsi-ta and I-hsing are of special value as witnesses of the penetration of Hindu mathematics in China. It is possible that the Hindu numerals were introduced into China at this time, though we have no positive evidence of it.'[40]

Hsi-ta's *Chiu-Chih-li* has also a new section entitled *Tui Yueh Chien Liang Ming* (on the prediction of the moon's positions) which reproduces the Indian sine table (actually sine differences) at intervals of 3°45′ for radius 3438′. The present author had the privilege of seeing this sine table in a microfilm copy of this rare manuscript in the working library of Professor Joseph Needham at Gonville and Caius College, Cambridge, U.K., and having the figures transcribed for him in Roman numerals by Professor Needham himself. The term *chia* represents the Chinese transcription of the Sanskrit *jyā* (sine difference), while the word *ping* is used to indicate sine difference. All the values given in the *Chiu-Chih-li*, except for values of *chia* and *ping* each, agreed with those given in the *Āryabhaṭīya*, the *Sūrya-siddhānta*, and similar works. Thus, along with the introduction of Indian astronomy and decimal numeration, trigonometrical sine and other functions were probably also introduced into China. These mathematical devices, it goes without saying, opened up new avenues of astronomical observations and computations. In the first quarter of the eighth century A.D. I-hsing, a Chinese Tāntric-Buddhist, was asked by the emperor to investigate the mathematical and other ideas introduced from India by Hsi-ta. Moreover, I-hsing and another astronomer, Nan Kung Yüeh, were ordered to carry out a meridian survey involving measurements of solstitial and equinoctial sun-shadows and of polar altitudes. All these observations involved the use of trigonometrical tables, and there is little doubt that I-hsing made the fullest use of the new knowledge transmitted to the astronomical circle.

Even here it was probably not a one-way traffic. Kaye has cited a number of parallel examples in Indian and Chinese texts and suggested that these passed into Indian mathematics from the Chinese.[41] Thus, *Chiu-chang Suan Shu* (Arithmetic in Nine Sections—second century B.C.) gives the area of a segment of a circle as $\frac{1}{2}(c+a)a$, where c is the chord and a the altitude of the segment, which is met with in Mahāvīra's *Gaṇitasāra-saṅgraha* (*c.* A.D. 850). Another

[40] G. Sarton, *Introduction to the History of Science*, Vol. I, pp. 504, 513, 514.
[41] G. R. Kaye, 'Indian Mathematics', *Isis*, Vol. II (1919), pp. 326-56.

arithmetical classic, the *Sun-Tzu Suan-Ching*, produced in the first century A.D., discusses the well-known remainder problem involving the solution of indeterminate equations of the first degree. An example given in the Chinese classic runs as follows: 'There are certain things whose number is unknown. Repeatedly divided by 3 the remainder is 2; by 5 the remainder is 3; and by 7 the remainder is 2. What will be the number?' Compare this with the following from Brahmagupta: 'What number divided by 6 has a remainder of 5, and divided by 5 has a remainder of 4, and by 4 a remainder of 3, and by 3 a remainder of 2?' With regard to these parallels, Mikami observed, on the basis of the anteriority of the Chinese texts, that 'the discoveries made in China may have touched the eyes of Hindoo scholars'.[42] Conclusions of this type from mere superficial parallelisms and similarities are rather hasty. While the Chinese arithmetical classics give a few numerical examples of the remainder problem without giving the method of solutions, this problem under the name of *kuṭṭaka* (pulverization, indeterminate equation) is discussed in detail from Āryabhaṭa (fifth century A.D.) onwards not through examples only, but giving the method of solving indeterminate equations of the first degree.[43] The method appears in Chinese mathematical works not before the thirteenth century A.D. Moreover, the germs of indeterminate equations first appear in India in connection with the construction of sacrificial altars (Śulvasūtras — *c.* 600-500 B.C.). The study of the problem received further impetus from its fruitful application in astronomy. However, pinpointing of transmission of ideas is generally a very difficult task, particularly in the ancient period. Needham has, therefore, wisely cautioned that intervals of time are often so long that independent development would have seemed equally likely.

From India to the Arab World and Latin Europe: When we come to the problem of transmission of ideas between India and the Arab world and Latin Europe in the medieval period, the problem appears to be simpler and less complicated because of the proximity of time. But this is not always so, and the task is beset with difficulties and pitfalls due to the insufficiency of records and the predilection of the scholar. Sachau's assertion that the foundation of Arabic literature was laid between A.D. 750 and 850 out of extensive foreign literature in which 'Greece, Persia, and India were taxed to help the sterility of the Arab mind'[44] might appear somewhat sweeping in character. But this is certainly not without some truth when we bear in mind the intensive and laborious effort of several polyglot translators, extending over two hundred years, in rendering Greek, Syriac, and Sanskrit texts in various branches of knowledge into Arabic. The Prophet had himself ordained in one of his

[42] Yoshio Mikami, *The Development of Mathematics in China and Japan* (Leipzig, 1912).
[43] See article on 'Post-Vedic Mathematics' in this volume.
[44] Sachau, *op. cit.*, p. XXVIII.

ḥadiths that knowledge must be sought from everywhere even if it be as far away as China.

When the Arabs embraced Islam, the knowledge of astronomy among them was in a primitive state being confined to the information about a few stars and lunar calendar for reckoning time. Their interest in scientific astronomy was possibly aroused when they came to learn that their neighbours, the Persians of the Sassanian period and the distant Hindus, had developed a scientific system of astronomy indispensable for making an accurate and reliable calendar. Ibn al-Adamī, in the preface to his book *Naẓm al-iqd*, tells us of the proficiency of Indian astronomers and the visit by one of them to the court of Caliph al-Mansūr to demonstrate his skills with globes, astronomical tables, computations of tables, etc. About this time a Persian (Pahlavi) book on astronomy, the *Ẓīk-i Shatro-ayār* was translated into Arabic under the title *Ẓīj ashshahriyār* by Ali ibn Ziyād al-Tamimī. The book was based on Hindu astronomical parameters and methods of computation as we have it from al-Bīrūnī. The *Ẓīj ashshahriyār* and the presence of an Indian astronomer in the Caliph's court were no doubt responsible for stimulating interest in Hindu astronomy among the Arabs. Shortly after these events, Brahmagupta's *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka* were translated, under the orders of the Caliph, into Arabic by Muḥammad ibn al-Fazārī (d. 796 or 806) and Ya'qub ibn Ṭariq (d. 796) under the titles of *Sindhind* and *Arkand* respectively. Although defective and corrupt and bitterly criticized by al-Bīrūnī two hundred years later, these initial efforts paved the way for further and more intensive study of Indian astronomy and mathematics by the Arabs. Kennedy in his excellent survey of Islamic astronomical tables has given an impressive list of such tables, either translations of, or based on, Hindu works, which were produced by both the eastern and western Arabs during the following centuries.[45]

Special mention may be made of al-Khwārizmī, one of the greatest mathematicians of the time, who was skilled in Sanskrit, developed great interest in Indian mathematics, produced an excellent astronomical *Ẓīj* based on Hindu parameters and methods of calculations, and rendered signal service to the cause of transmission of Indian astronomy and mathematics, first among the Arabs, and subsequently in Europe through Latin translations of his works. Al-Kindī, distinguished contemporary of al-Khwārizmī, wrote four books on the use of the Hindu numerals and computation—*Ḥisābu'l hindi.* Ḥabash al-Ḥāsib, al-Nairizi, al-Ḥasan ibn Miṣbāh, and several others also produced works on Indian astronomical tables and mathematics. But from the point of view of a synthetic and critical study of India's contribution to science

[45] E. S. Kennedy, 'A Survey of Islamic Astronomical Tables', *Transactions of the American Philosophical Society*, n.s. XLVI (1956), pp. 123-77.

in general and to astronomy and mathematics in particular, the encyclopaedic scientist and indologist al-Bīrūnī surpassed them all. Interest in Hindu astronomy and mathematics declined among the eastern Arabs after the availability of Greek works in translations, but it continued unabated among the western Arabs of Spain which became the focal point in the transmission of Indian ideas to Latin Europe.

In the transmission of Hindu astronomy and mathematics to Latin Europe, Adelard of Bath (*c.* 1142), John of Seville (*c.* 1135), Robert of Chester (*c.* 1141), Villedieu (*c.* 1240), Sacrobosco, and Leonardo Pisano played the most notable part. Adelard was an English philosopher, mathematician, and scientist. He prepared a Latin translation of al-Khwārizmī's astronomical tables in the version of Maslama al-Majrītī of Spain, which is now available in German and English translations. These tables exemplify how al-Khwārizmī syncretized Greek and Hindu knowledge of astronomy. The meridian of Ujjayinī, Arin in Arabic, is taken to be of zero longitude in Hindu astronomy. The era of Kaliyuga (17 February 3102 B.C.) has become the 'Era of Flood'. The *ahargaṇa* method of computing the mean positions of a planet (*elwazat*), the computations of true positions with the help of trigonometrical tables, and their refinements by arithmetical methods as taught by Āryabhaṭa, Brahmagupta, and others were thus introduced into European circles of scholars. In 1951 Lynn Thorndike brought to light an anonymous fifteenth-century Latin MS Ashmole 191 II which begins the Era of Flood from 17 February 3102 B.C., the starting-point of the Kaliyuga era, and uses Hindu sines for radius equalling 150 and Hindu trigonometrical methods for calculating equinoctial noon shadows. The Newminster manuscript is thus another instance of transmission of Hindu astronomical methods to Europe possibly through Arabic intermediaries, as late as the fifteenth century A.D.

Adelard probably translated an arithmetical work, attributed to al-Khwārizmī, under the title *Liber Ysagogarum*, and pioneered the transmission of Indian arithmetic along with the system of decimal numeration. But more popular was the *Algoritmi de numero Indorum* representing an earlier Latin translation, of which the translator is unknown. John of Seville was well known for his *Liber algorismi*, another arithmetical work based on al-Khwārizmī and other Arabic sources. Robert of Chester introduced the study of algebra in Latin Europe by translating the same Arab author's algebraic treatise *Ḥisāb al-jabr wal-muqābala*; this work drew upon Hindu as well as other sources (old Babylonian tradition). Villedieu's *Carmen de algorismo* had many things in common with John's *algorismi* and was composed in metric form (hexameter). John Sacrobosco, Villedieu's contemporary, produced another arithmetical tract *Algorismus vulgaris*, which attained considerable popularity in England and other parts of Europe. Finally, we have Leonardo Pisano's celebrated work

Liber abaci (*c.* A.D. 1202), an arithmetical classic of the Middle Ages seeking to provide a clear and lucid exposition of oriental arithmetic, mainly Indian and Arabic, including decimal place-value numeration.

The word 'algorism' needs some explanation. This was the medieval name for the new arithmetic based on decimal place-value numeration. The efforts of Adelard, John, Robert, Villedieu, Sacrobosco, and Leonardo, confined to the twelfth and thirteenth centuries A.D., did not immediately develop into a sort of mathematical movement. That took place in the sixteenth century and coincided with the Renaissance when expanding trade and commerce generated new demands for easy arithmetical calculations. This is corroborated by the sudden appearance in quantity (due to printing) of arithmetical works in most European countries from the sixteenth century onwards. Some examples are: Cardano's *Practica arithmetice et mensurandi singularis* (1501) and Tartaglia's *La Prima Parte del general trattato di numeri e misure* (1556), in Italy; Robert Recorde's *The grounde of artes, teachyng the worke and practise of arithmetike* (*c.* sixteenth century) and Digg's *Stratiolios* (1579) in England; Jacob Köbel's *Rechenbiechlin* (1514), Stifel's *Arithmetica integra* (1514), and Christopher Clavias's *Epitome arithmeticae practice* (1583), in Germany; and Boissiere's *L'art d'arythmétique* (1554) and Forcadel's *L'Arithmétique*, in France.[46] Elementary as these tracts may now appear, their potentialities were soon felt in the rising trade and commerce of the period, in the teaching programmes of universities, and in original mathematical research in general.

To sum up, scientific knowledge always tends to be international. If it is unquestionable in today's scientific research endeavour, it was no less so in ancient and medieval times. Through innumerable seminars, conferences, and congresses, reprints from periodicals, and monographs scientific ideas and methods travel nowadays with incredible speed. This speed could not of course be expected of the times we have been talking of. Yet ideas travelled over the deserts and mountains and across the seas, and savants of distant lands somehow knew what their confrères elsewhere thought about the mysteries of nature and about man and his environment.

[46] S. N. Sen, 'Indian Elements in European Renaissance', *Organon*, Vol. IV (1967), pp. 55-59.

PART II

SCIENCE AND TECHNOLOGY IN MODERN INDIA

17

MATHEMATICS

MATHEMATICS, as we have seen, made considerable progress as a discipline in ancient and medieval India. Up to the fifteenth or sixteenth century A.D. India was a leading country in the world in mathematics. At the beginning of the twentieth century work in the field of mathematics began along modern lines under the inspiration of Indian students who had made higher studies in the discipline abroad. Research work started in India after the founding of the Indian Mathematical Society in 1907 by V. Ramaswami Aiyar and a band of enthusiasts, including R. P. Paranjpye, Senior Wrangler (Cambridge University), M. T. Naraniengar, Balak Ram, P. V. Seshu Iyer, K. T. Sanjana, and Hanumantha Rao, and others. This served as a stimulus for the foundation of the Calcutta Mathematical Society in 1908 by Asutosh Mookerjee, Vice-Chancellor, Calcutta University, who was himself a mathematician of high order and well known for his contribution to differential equations and for his geometrical interpretation of Monge's differential equation of conics. Another society called the Banaras Mathematical Society (later Bharat Ganita Parishad) was founded in 1916 by Ganesh Prasad who studied mathematics at Gottingen, Germany, and was the most outstanding mathematician of northern India of his time. The modern mathematical research work done in this country has been incorporated mostly in the *Journal of the Indian Mathematical Society*, the *Bulletin of the Calcutta Mathematical Society*, and the *Proceedings of the Banaras Mathematical Society*. Papers on mathematics have also been published in the *Proceedings of the National Institute of Sciences*, *Proceedings of the Indian Academy of Sciences*, and *Proceedings of the National Academy of Sciences*. India produced in this period Srinivasa Ramanujan (1887-1920) whose early death was the greatest blow to the study of mathematics in recent times. Ramanujan made such outstanding contributions to the theory of numbers, partitions, the theory of elliptic, and modular functions that Professor Hardy of Cambridge University, a leading mathematician of world fame, wrote: 'His (Ramanujan's) work has one gift which no one can deny, profound and invincible originality; on this side, most certainly I have never met his equal and I can only compare him with Euler and Jacobi. European mathematicians will take fifty years to decipher what is contained in his notebooks.' The three notebooks of Ramanujan were published unedited by the Tata Institute of Fundamental Research, Bombay, in 1962. Ramanujan's early contributions appeared in the *Journal of the Indian Mathematical Society*. His first paper entitled 'Some Properties of Bernoulli's Numbers' published in 1911 attracted great attention.

THEORY OF NUMBERS

Ramanujan's work was continued by many noted mathematicians. S. Chowla and S. S. Pillai made important contributions to various topics in the theory of numbers. Chowla found a new proof of Von-Sundt's theorem, some properties of Eulerian numbers, and generalization of a theorem of Wolstenholme. He also discussed Waring's theorem on cubes and rational solutions of $ax^n-by^n=k$. He gave solutions of a problem of Erdos and Turan in additive number theory and found a new proof of a theorem of Siegel. He also worked on biquadratic residues and the theory of the Riemann Zeta function, and discussed Waring's problem (mod p). S. S. Pillai wrote several important papers on normal numbers, algebraic irrationals, diophantine equation, and Waring's problem. He also studied the problem of lattice points in a right-angled triangle. T. Vijayaraghavan worked on decimals of irrational numbers. He and Chowla jointly studied the complete factorization (mod p) of cyclotonic polynomial of order p^2-1. K. G. Ramanathan worked on the congruence property of Ramanujan's function $\tau(n)$. He also studied some of Ramanujan's trigonometric sums $C_m(n)$ and their applications. Hansraj Gupta developed the partition theory and prepared tables of partitions. He worked on some idiosyncratic numbers of Ramanujan and studied congruence properties of $\sigma(n)$, $\tau(n)$ and also prepared a table of values of $\tau(n)$. R. D. Bambah made important contributions to the theory of geometry of numbers. He obtained a congruence property of Ramanujan's function. He and Chowla considered Ramanujan's function, congruence properties of Ramanujan's function, and the sign of Gaussian sum. V. Ramaswamy studied the properties of integers $\geqslant X$ and free of prime divisors $>X^c$. Krishnaswamy Iengar studied the theory of the nearest square continued fraction. He discovered the congruence properties of Ramanujan's function $\tau(n)$ and also discussed non-Ramanujan congruence properties of the partition function. D. P. Banerji worked on congruence property of Ramanujan's function $\tau(n)$ and obtained some new properties of it. P. K. Menon obtained several congruence theorems and some theorems on residues. He studied arithmetic functions and congruence properties of the ϕ-function. He gave generalizations of Wilson's theorem and divisor function. D. R. Kaprekar, C. S. Venkataraman, K. Subbarao, S. Sastry and Balasubramanium, F. C. Auluck, K. Padmavalli, V. S. Nanda, and Venugopal Rao contributed to the theory of numbers.

ALGEBRA

Notable work has been done in algebra by a large number of Indian mathematicians. R. Vaidyanathaswami contributed to this subject in general and matrix algebra in particular. He obtained a remarkable property of integers mod N and its bearing on group theory. He studied the rank of the

double binary forms, bilinear and double bilinear forms, and the null pencil of binary quartics. He investigated the quadratic reciprocity of polynomials and wrote on Quasi-Boolean algebras and many valued logics. He also worked on the ideal theory of partially ordered sets and arithmetic function. A. Narasinga Rao discussed Boolean matrix algebra. S. Chakravarty, S. Krishnamurty Rao, K. N. Ghosh, K. Balachandran, C. Krishnamachari, M. Venkataramier, M. Bhimasena Rao, P. O. Upadhyaya, and M. V. Ayyar worked on special types of determinants. S. Pankajam discussed ideal theory of Boolean algebra and its application to reductive system. D. P. Banerji considered the self-inverse module. Harish Chandra investigated the representations of the Lie algebras, radical of a Lie algebra, the Tannaka duality theorem and faithful representations of Lie groups, algebra of Dirac matrices, and algebra of Meson matrices. Pandit Hemraj worked on cubics and biquadratics. S. Chowla studied the irrational indefinite quadratic forms. F. W. Levi wrote a treatise on modern algebra and studied the properties of a Skew field of a given degree. V. S. Krishnan investigated the extension of partially ordered sets, partially ordered algebras, and the equivalence of any representation to an abstract structure. He also discussed many of the properties of ideals in rings and distributive lattice that hold in any commutative ringoid. M. Venkataraman worked on abstract algebra. M. T. Naraniengar discussed certain important properties of polynomials, cyclic equations, and cyclotonic equations. B. S. Madhava Rao, Thiruvenkatachar, and Venkatachal Aiyengar discussed some aspects of non-commutative algebras. B. S. Madhava Rao investigated algebra of elementary particles. K. N. Srinivasa Rao, C. Srinivasan, K. S. Banerji, Q. M. Hussain, R. Ratnam, P. M. Roy, S. M. Shah, A. R. Ansari, M. Ishaq, C. R. Marathe, and S. N. Roy worked on matrices and different aspects of algebra. R. C. Bose, S. S. Shrikhande, and K. N. Bhattacharya studied group divisible and incomplete block designs. T. V. Narayana discussed combinatorial problems and their application to the probability theory. P. K. Ghosh discussed deduction and evaluation of a certain type of complex roots by Graffe's root squaring method. K. G. Ramanathan contributed to quadratic forms over involutorial division algebras. He considered the Riemann sphere in metric spaces and the convergence properties of $\sigma_s(N)$. He also worked on units of fixed points in involutorial algebras and product of elements in finite Alelian groups. M. Ziauddin prepared tables of symmetric functions for statistical purposes. S. M. Kerwala prepared tables of monomial symmetrical function of various weights. He also worked on self-conjugate latin squares of prime degree and the asymptotic number of three-deep latin rectangles.

GEOMETRY

V. Ramaswami Aiyar, T. Narayanienger, M. Bhimasena Rao, A. A. Krishnaswami Iyengar, and N. Dorairajan contributed to elementary geometry in general and the geometry of the triangle in particular. The modern viewpoint in algebraic geometry was dealt with by C. V. H. Rao, R. Vaidyanathaswami, A. Narasinga Rao, B. S. Madhava Rao, and their pupils. In particular, R. Vaidyanathaswami and P. K. Menon did important work on the invariant geometry of the rational (norm curve). Sahib Ram Mandan worked on distance geometry. F. W. Levi, W. H. Young, and S. K. Abhyankar worked on algebraic geometry. M. Venkataraman studied the axiomatic development of Euclidean geometry.

Important work on differential geometry was done by Asutosh Mookerjee, Shyamadas Mukhopadhyaya, Haridas Bagchi, C. N. Srinivas Ienger, B. Ramamurti, V. Rangachariar, D. D. Kosambi, Ram Behari, R. S. Misra, R. N. Sen, and others. Shyamadas Mukhopadhyaya and his pupils contributed to differential geometry in plane and hyperspace and elementary non-Euclidean geometry. The differential geometry of curves and surfaces was also studied by some of Ganesh Prasad's pupils like Bholanath Pal and Harendranath Datta. D. D. Kosambi worked on the geometry of paths and initiated work on spaces now known as Kawaguchi spaces. He generalized the concept of isotropy in generalized path spaces. C. N. Srinivas Ienger considered some properties of rectilinear congruences. B. Ramamurti studied line of striction and spinors. V. Rangachariar investigated properties of conicoids of a pencil touching a given plane and worked on rectilinear congruences.

Ram Behari wrote a series of papers on the differential geometry of ruled surfaces and rectilinear congruences. He gave generalizations of the theorems of Malus-Dupin, Beltrami, and Ribacour. He found the condition that the osculating quadrics of a ruled surface might be equilateral, and discovered a new geometrical meaning of Laguerre's function. He applied the method of tensor analysis to find the properties of rectilinear congruences. The theory of 'pitch of a congruence at a ray' was developed and a relation between the pitch of a pencil of a congruence and Levi-Civita's 'Anormalita' of a congruence was established by him. He set up a school of differential geometry and theory of relativity in Delhi, prominent products of which are R. S. Misra, P. B. Bhattacharya, M. K. Singhar, S. C. Saxena, Gita Halder, Nirmala Prakash, R. N. Kaul, Kamalamma, and K. K. Gorowara.

R. Vaidyanathaswami studied the simplexes doubly incident with a quadric and the number of lines which meet four regions in hyperspace. K. Rangaswami Iyer discussed linear complexes, net of tetrahedra, and geometry of cylindroid and conormal triads. The field of differential geometry was extended to unified field theory by R. S. Misra who gave a solution of Einstein's

field equations and guided several workers, among whom mention may be made of Srikishan, Upadhyaya, S. Izhar Hussain, S. K. Kaul, and K. D. Singh. Nirmala Prakash and A. C. Shamihoke published several papers on Finsler spaces.

B. M. Sen worked on continuous deformation of surfaces. R. N. Sen discussed the connection between Levi-Civita's parallelism and Einstein's teleparallelism. He also wrote about curvature of hypersurfaces and rotations in hyperspace. He developed a school of geometry in general and differential geometry in particular at Calcutta. M. C. Chaki contributed to the differential geometry of recurrent, Ricci-recurrent, and special types of Riemann spaces. B. R. Srinivasan contributed to the lattice point problem of many-dimensional hyperboloids. A. C. Choudhary worked on the geometry of the web.

ANALYSIS, DIFFERENTIAL EQUATIONS, THEORY OF FUNCTIONS, ETC.

In analysis Ganesh Prasad's pioneering work covered a wide field including the theory of functions of a real variable, elliptic functions, Fourier series, harmonic analysis, and the theory of the potential. Numerous pupils and co-workers followed up his work in these directions. Continuity and derivability of functions were dealt with by A. N. Singh, Laxmi Narain, R. D. Misra, and P. D. Shukla. A. N. Singh also discussed problems connected with the summability of Fourier series. Among those who studied harmonic analysis, special forms of harmonic functions, elliptic and other special functions were S. C. Dhar, Bholanath Pal, Gorakh Prasad, R. S. Varma, Abani Bhushan Datta, N. G. Shabde, K. S. K. Iyengar, P. K. Menon, P. K. Ghosh, and S. N. Roy. D. P. Banerji discussed the generalizations of Weirstrass's non-differentiable functions and also the applications of operational calculus. M. R. Parameswaram considered the properties of transforms over a series of spaces, Mazur and Orlicz summability, Tauberian theorems for summable functions, and a comparison between the Cesaro and Borel methods of summability. M. S. Ramanujam dealt with total translativity of Hausdroff methods. J. A. Siddiqi, B. N. Shaney, S. R. Sinha, and Sulakshana Kumari studied the summability methods. P. L. Srivastava worked on Dirichlet's series, analytic continuation, integral functions, and divergent series. B. N. Prasad contributed to and established a school of Fourier series and Fourier analysis at Allahabad and inspired a large number of workers, prominent among whom were U. N. Singh, J. A. Siddiqi, and T. Pati. T. Pati studied absolute Riez summability, absolute summability, and absolute factors in summability series. U. N. Singh discussed the summability of Fourier series and derived series of Fourier series. R. Mohanty at Cuttack worked on Fourier series and integrals. Brij Mohan at Banaras worked on self-reciprocal functions. A school of special functions, calculus of transforms, Laplace and Hankel transforms was developed at

Lucknow by R. S. Varma, S. C. Mitra, R. P. Agarwal, S. K. Bose, K. S. Shukla, and Ram Kumar. Contributions to the convergence and summability of infinite series were made in South India by K. Ananda Rao, K. B. Madhava, T. Vijayaraghavan, V. Ramaswamy, V. Ganapathi Iyer, Thiruvenkatachar, V. S. Krishnan, Meenakshisundaram, and Venkatachal Aiyengar.

C. T. Rajgopal and C. Racine worked on analysis. G. S. Mahajani and Ram Behari obtained an interesting result in the logarithmic expansion. K. Chandrasekharan, K. G. Ramanathan, Balagangadharan, and Sridharan established a school of summability theory, number theory, function theory, modern algebra, and topology at the Tata Institute of Fundamental Research at Bombay. R. Vaidyanathaswami, Singbal, T. P. Srinivasan, M. S. Ramanujam, R. Narasimhan, and S. Swaminathan also worked on topology. V. Ganapathi Iyer investigated singular and integral functions. S. Meenakshisundaram studied non-linear partial differential equations of the parabolic type and Fourier Ansatz. He developed the theory of expansion of an arbitrary function in a series of Eigen functions of boundary value problems and gave a new summation process. In collaboration with C. T. Rajgopal, he made some investigation on a Tauberian theorem of K. Ananda Rao and extended a Tauberian theorem of L. J. Mordell. K. Chandrasekharan and Meenakshisundaram produced a standard work on typical means. D. D. Kosambi worked on partial differential equations. M. R. Siddiqi made a significant contribution to the theory of non-linear partial differential equations. S. K. Mitra and Shanti Ram Mukherji dealt with some differential equations arising in viscous hydrodynamic flow. B. N. Bose, Haridas Bagchi, F. C. Auluck, S. K. Bose, K. Chandrasekharan, K. S. K. Iyengar, D. D. Kosambi, S. Meenakshisundaram, A. A. Krishnaswami Iyengar, C. T. Rajgopal, and K. Ananda Rao worked on the theory of infinite series.

S. M. Shah, S. Meenakshisundaram, C. N. Srinivas Ienger, R. S. Varma, V. Lakshmikantham, K. Padmavalli, S. K. Singh, V. Ganapathi Iyer, K. S. K. Iyengar, and S. K. Bose worked on the properties of integral functions. K. Chandrasekharan and C. T. Rajgopal worked on Hadamard's factorization theorem. S. C. Dhar and Hari Shankar dealt with parabolic cylinder functions and Whittaker and Weber functions. N. G. Shabde worked on integrals involving Legendre and Bessel functions, confluent hypergeometric functions, and Laguerre functions. N. A. Shastri studied Bateman's polynomials, Angelesen's polynomial $\pi_n(x)$, Bessel functions of third order and confluent hypergeometric series, and products of Legendre's functions. R. S. Varma worked on Whittaker's functions and Weber's parabolic cylinder functions. B. R. Pasricha worked on Humbert functions and Whittaker functions. J. L. Sharma worked on Lame's equation, Lame's functions and recurrence for-

mulae for generalized Lame's functions, and gave integral equations for Whittaker's confluent hypergeometric functions. S. Sinha studied infinite integrals involving Bessel and hypergeometric functions. H. C. Gupta worked on Bessel functions and operational calculus. P. K. Menon gave a generalization of Legendre functions. Haridas Bagchi applied the method of difference equations to the summation of certain series involving Legendre and Bessel functions. S. C. Mitra studied certain infinite integrals involving Struve functions and parabolic functions. He discussed certain expansions involving Whittaker's M-functions and worked on certain transformations in generalized hypergeometric series. S. P. Kaushik gave a generalization of the Laplace transform. S. K. Bose worked on generalized Laplace transform. R. P. Agarwal made a study of Hankel transform and self-reciprocal functions. K. M. Saxena worked on the theory of Laplace Stieltjes integral. V. Singh worked on Appell polynomials and generalized Laplace integrals. C. B. Rathie worked on Laplace's integral and its generalizations.

APPLIED MATHEMATICS

S. N. Bose, S. Chandrasekhar, D. S. Kothari, N. R. Sen, B. M. Sen, Nagendranath, B. B. Sen, F. C. Auluck, S. K. Banerji, A. C. Banerji, P. L. Bhatnagar, R. S. Varma, N. L. Ghosh, B. R. Seth, and G. Bandyopadhyaya initiated and inspired considerable work on applied mathematics, specially potential theory, hydrodynamics, magneto-hydrodynamics, optics, wave-propagation, plasma-physics, and allied branches of theoretical physics. B. B. Datta Mazumdar, N. M. Basu, Subodh Chandra Mitra, S. Ghosh, N. N. Ghosh, J. M. Ghosh, Ram Ballabh, M. Ray, G. L. Saini, Chandrika Prasad, J. N. Kapur, and P. C. Jain were some of the other workers in applied mathematics. Savoor studied the stability of the pear-shaped figure of equilibrium of a rotating fluid. N. R. Sen considered a number of problems of gas dynamics, boundary layer theory turbulence, and magneto-hydrodynamics. He established a school of ballistics electricity and magnetism, and hydrodynamics at Calcutta. B. R. Seth worked on Navier-Stokes equations, boundary layer theory, fluid flow problems, and waves in canals. He built up a school of hydrodynamics, elasticity, and high speed computation at Kharagpur. G. Bandyopadhyaya, M. K. Jain, R. P. Kanwal, Y. D. Wadhwa, R. S. Nanda, P. D. S. Verma, and S. D. Nigam were among others who worked in this field at Kharagpur.

P. L. Bhatnagar contributed to fluid mechanics, magneto-hydrodynamics, ballistics, astrophysics, and plasma-physics. His contribution to Botemann equation is referred to as B. G. K. (Bhatnagar, Gross, Krook) model for collisions. His work on secondary flows in non-Newtonian fluids provides a method

of determining non-Newtonian viscosities. He also contributed to heat transfers in linear surface.

S. Chandrasekhar made outstanding contributions in many branches of applied mathematics, including astrophysics, astronomy, hydromechanics, and turbulence. Ram Ballabh and P. C. Jain worked on super-possibility of fluids. V. R. Thiruvenkatachar, J. N. Kapur, G. L. Saini, N. L. Ghosh, M. Ray, S. K. Roy, and H. Sircar also worked on hydrodynamics. S. N. Barua worked on rotating fluids. S. L. Malurkar made a study of the dynamics of thunderstorms.

ELASTICITY AND PLASTICITY

B. R. Seth wrote a monograph on two-dimensional potential problems connected with rectilinear boundaries. He studied bending plates with various types of boundaries, transfer of vibrations, and stability of rectilinear plates. I. D. Seth worked on the reflection and refraction of attenuated waves in semi-infinite elastic solid medium. B. B. Sen investigated stresses in elastic discs of a variety of shapes. He studied the uniqueness theorem for problems of thin plates bent by normal pressures and also studied boundary value problems and circular discs under body forces. S. Ghosh investigated plane strain and plane stress in aeolotropic plates. He discussed the torsion and flexure of beams whose cross-sections are bounded by specified contours. S. D. Chopra worked on various problems of elasticity. D. N. Mitra, G. Paria, A. M. Sen Gupta, H. M. Sen Gupta, P. D. S. Verma, R. D. Bhargava, S. K. Roy, and R. S. Dhaliwal also contributed to the theory of elasticity. Romola Bhor worked on plasticity. J. Ramakanth and V. Lakshmikantham extended Seth's results to aeolotropic and isotropic hollow composite bodies by considering problems of cylinders and spheres. B. R. Sen obtained important design results in the failure of reinforced concrete beams. V. Cadambe studied the flexure of a thin elastic plate under specified directions. N. N. Ghosh developed a matrix method of analysing strain and stress in hyperspace.

THEORY OF RELATIVITY

In the field of relativity S. N. Bose made an important contribution to Einstein's unified field theory. He considered the problem of the g-Γ linear relation and obtained the solution with the aid of matrix methods and also suggested an alternative unified theory wherein the torsion vector does not vanish. V. V. Narlikar generalized Schwarzschild's solution and found some new properties of the world trajectories of Milne's theory. He discussed the question of stability of a particle in gravitational field and investigated different laws which will remain invariant under the generalized infinitesimal Lorentz transformation. He investigated whether Einstein's theory is consistent with

the geodesic postulate and discussed the gravitational equations of motion in relativity. He and Ramji Tewari showed that there is no interaction between the gravitational field and the electromagnetic field up to the second order of approximations.

N. R. Sen suggested that the expansion of the Einstein Universe could have been started by the condensation of diffuse matter into nebulae. He investigated the stability of cosmological models.

R. S. Misra considered the problems of comparison of the field equations of Einstein's and Schrodinger's unified theory, and basic principles of unified theory. He developed the method of 'repeated substitution' for tackling the g-Γ linear relation in Einstein's unified theory. He and Izhar Hussain considered the problem of projective change of affined connections in Einstein's unified field.

G. Bandyopadhyaya studied in particular exact solutions of Einstein's unified theory. His observations regarding point-charge in non-symmetric field theory attracted the attention of E. Schrodinger and A. Papapetrou who suggested a modified interpretation in the unified field theory.

P. C. Vaidya investigated the external field of a radiating star in general relativity and studied the radiational, gravitational, and electromagnetic effects in the general theory of relativity.

A. Roy Choudhuri discussed condensations in expanding cosmological models, radiation sphere in Einstein Universe, relativistic cosmology, and anisotropic cosmological solution in general relativity. Dutta Mazumdar discussed the relativistic analogue of Earnshaw's theorem and also obtained a rigorous solution of general relativity. S. N. Gupta investigated quantization of Einstein's gravitational field, gravitation, and electro-magnetism, and comparison of the theories of gravitation propounded by Einstein and others. Ram Behari and S. C. Saxena studied field equations of Einstein's unified theory using Eisenhart's generalized Riemann space. S. M. Sulaiman, applying Newtonian principle and starting with the fundamental assumption of the finiteness of the velocity of gravitation, derived the same law as that of Einstein for the motion of heavenly bodies. He showed that deflection of a light ray due to the sun's gravitational field is between 4/3 and 3/2 times Einstein's value while the shift of the line to the red is $(1+\mathrm{Sin}^2\alpha)$ times Einstein's value where α is the angle between the line of sight and the radius vector to the point on the sun's disc on which observation is made.

Among others who contributed to the general theory of relativity were J. Ghosh, S. C. Kar, N. K. Chatterji, D. N. Moghe, K. Nagabhushanam, A. C. Banerji, K. R. Karmakar, K. P. Singh, B. R. Rao, K. B. Shah, I. M. Pandya, S. R. Roy, N. N. Ghosh, S. C. Dhar, J. P. Jaiswal, D. K. Sen, K. B. Lal, Alladi Ramakrishnan, and L. Radhakrishna.

Jayant Vishnu Narlikar together with Fred Hoyle made a historical discovery in propounding a new theory of gravitation which may necessitate a drastic revision in Einstein's theory of gravitation.

ASTRONOMY, STATISTICS

A. C. Banerji and Nizamuddin considered two models of Jupiter's atmosphere, viz. adiabatic and isothermal. A. C. Banerji and P. L. Bhatnagar gave theories of the origin of the solar system. D. S. Kothari and P. L. Bhatnagar discussed Rosseland's theory of anharmonic oscillations of a gaseous star and studied white dwarf stars. Among other contributors may be mentioned U. R. Burman, S. K. Roy, H. K. Sen, N. L. Ghosh, Gorakh Prasad, Chandrika Prasad, H. K. Ganguly, D. N. Moghe, G. Bandyopadhyaya, S. W. Shiveshwarkar, and R. S. Kushwaha.

P. C. Mahalanobis founded a school of statistics at Calcutta, which later developed into the famous Indian Statistical Institute. Important work on this subject is being done at different centres of this Institute.

BALLISTICS AND OPERATIONAL RESEARCH

In both ballistics and operational research, especially Queing theory, R. S. Varma did pioneering work and inspired many young scientists, among whom is Shiv Kumar Gupta, who has contributed to inventory control and wrote a book on mathematics for modern management.

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ASTRONOMY

ASTRONOMY is one of the sciences which had been studied in India from very ancient times and to which the Indians had made notable contributions. The achievements of Āryabhaṭa, Varāhamihira, Brahmagupta, and Bhāskara II are monumental and have been covered earlier in this volume. Little, if any, astronomical activity existed in India over the next five centuries until Jai Singh (1686-1743) performed the incredible feat of building five observatories and making accurate observations with them in a little less than four decades. These institutions contain enormous instruments of masonry, many of which were invented by Jai Singh himself, and were meant to mutually confirm and check the observations made. Though magnificent in concept, they were seldom used after Jai Singh, and with the new era of telescope technology already a hundred years old, they retreated rapidly into obsolescence. One can only wonder what a Jai Singh, better informed of contemporary happenings, would have left behind to posterity.

The study of astronomy and allied sciences reassumed importance in India with the establishment and gradual expansion of the suzerainty of the East India Company. Thomas Deane Pearse (1741-89) of the Bengal Artillery undertook a series of observations of latitudes and longitudes from 1774 to 1779 and again from 1781 to 1784 during his marches to and from Madras in the Mysore War. William Petrie, a member of the Madras Government, started another series of observations in 1787. He had in his possession two three-inch achromatic telescopes, two astronomical clocks with pendulums, and an excellent transit instrument. This equipment formed the nucleus of instrumentation of the first observatory established in Madras in 1790 by Michael Topping for promoting the knowledge of astronomy, geography, and navigation. The authorities of the Company found it necessary to prepare accurate maps of the territory under their control and of the subcontinent in general. This required accurate determination of longitudes and latitudes of important places. The Madras observatory, the building of which was completed in 1792 by Sir Charles Oakeley, then President of the Council, soon embarked on a series of observations of the stars, the moon, and eclipses of Jupiter's satellites with the accurate determination of longitude as its first concern. The pier that carried the original small transit instrument is a massive granite pillar and has on it an inscription in Latin, Tamil, Telugu, and Hindi so that 'posterity may be informed a thousand years hence of the period when the mathematical sciences were first planted by British Liberality in Asia'. In any case, this quotation from the first annual report of the observatory is at least a record of the

fact that astronomical activity at the Madras observatory was indeed the first among British efforts at scientific studies in India.

The longitude of the Madras observatory has a most important role as a fundamental meridian from which observations for longitude in the Indian survey are reckoned. The accuracy with which a map of India fits into a map of the world depends solely on the accuracy of the longitude determination of the transit instrument pier at the Madras observatory. The work of the great Trigonometrical Survey of India commenced at Madras on 10 April 1802 when a base line measurement related to the Madras longitude was made.

For over a century the Madras observatory continued to be the only astronomical observatory in India engaged in systematic determination of star position and brightness. Goldingham, Taylor, Jacob, and Pogson were the Government astronomers who dominated the activity at Madras. With a new 5-foot transit, Taylor completed in 1844 his catalogue of the positions of over 11,000 stars. Jacob's principal interest lay in double stars: the preparation of their catalogues, measurement of their separation, and determination of their orbits. The observatory received during his tenure a new meridian circle and with it commenced a series of observations of the satellites of Jupiter and Saturn as well as those for the determination of star position and evaluation of proper motions. From 1861 until his death in 1891, Pogson explored new areas of observations. While the transit instrument and the meridian circle were utilized for cataloguing 3,000 stars that included standard stars, large proper motion stars, variable stars, and the like, it is with the new 8-inch Cooke equatorial that he made discoveries of asteroids and variable stars. The asteroids Asia, Sappho, Sylvia, Camilla, and Vera, and the variable stars Y Virginis, U Scorpii, T Sagittari, Z Virginis, X Capricorni, and R Reticuli were all first discovered visually at Madras either with the transit instrument or by the equatorial instruments. The discovery in 1867 of the light variation of R Reticuli by C. Raghunathachary is perhaps the first astronomical discovery by an Indian in recent history. Pogson also undertook the preparation of a catalogue and atlas of variable stars, complete with magnitude estimates made by him of both the comparison and the variable. These were edited by Turner after Pogson's death.

During this period the Madras observatory participated in observations of the important total solar eclipses that were visible from India. These were the eclipses that established the foundations of astrophysics and especially of solar physics. In these observations the Madras observatory's contributions were most significant, as will be seen later.

In those days an Indian Observatories Committee in England advised the Secretary of State on matters pertaining to the administration of the Madras observatory. Without adequate staff to help him, Pogson had taken on more

programmes of work than he could bring to a successful termination. Questions were raised in London in 1867 whether the Madras observatory should be continued at all since the British had started some other observatories in the Southern Hemisphere. It was even recommended that the Madras observatory should concentrate more on publication of the observations already made than make new ones. The work of Pogson was commended and questions on the closure of the Madras observatory were relegated to the time when Pogson would retire.

In May 1882 Pogson emphasized the need for a 20-inch telescope which could be located at a hill station in South India and used for photography and spectrography of the sun and the stars. The proposal received active support in both India and Britain, and the search for a suitable location in the southern highlands of India began. Michie Smith undertook the survey of the Palni and Nilgiri Hills in 1883 and 1885, his observations covering both the requirements of transparency and steadiness of image during both day and night. But in 1884 the Astronomer Royal recommended that because Pogson had accumulated large arrears in observations, it would not be desirable to saddle him with additional work connected with the new large equatorial and that the question of establishing a branch observatory or removing the Madras observatory to a more favourable site might be considered on Pogson's retirement. The Astronomer Royal preferred the latter alternative.

The idea of making solar observations under tropical skies soon gained ground and the search for a suitable site extended over the entire Indian subcontinent. In the north Leh, Mussoorie, and Dehra Dun were examined for their suitability. In the south the study was confined to Kodaikanal, Kotagiri, and Madras. The Leh and Mussoorie observations indicated that the skies were seldom free of dust to permit observations that called for high transparency. And so the new observatory had to be located in the southern hills with Kodaikanal as the obvious choice on the basis of performance. At the Indian Observatories Committee meeting of 20 July 1893, with Lord Kelvin in the chair, the decision was taken to establish a solar physics observatory at Kodaikanal with Michie Smith as its superintendent. The decision on a permanent site of the astronomical observatory was deferred to a later date. The observatory was to be under the control of the Government of India instead of the Government of Madras, as it had been for a century.

KODAIKANAL OBSERVATORY

The last five years of the nineteenth century witnessed a rapid transference of work from the Madras observatory to Kodaikanal. The first observations at Kodaikanal commenced in 1901. While the two observatories functioned together under the control of a director at Kodaikanal, the astronomical observa-

tions at Madras were confined only to the measurement of time. The new observatory had a wide array of spectroscopic equipment specially acquired for solar studies. There were instruments to visually examine the prominences around the solar limb and the spectra of sunspots. Photographic studies included daily white light photography of the solar disc and monochromatic chromospheric pictures with the spectroheliographs in the light of ionized calcium and of hydrogen. This series of photographs continues uninterrupted to this day and forms one of the most unique collections of a record of solar activity available in the world. Only two other institutions, the observatory at Meudon in Paris and the Mount Wilson observatory in California, have collections that span an equivalent time interval.

Perhaps the most important result of these early years was the discovery by Evershed at Kodaikanal in 1909 of radial motion in sunspots. In the next few years numerous studies of this phenomenon, now known as the Evershed Effect, were made at both Kodaikanal and a temporary field station in Kashmir. These early studies were so comprehensive that little has been added to our information on the subject in the subsequent half century. In 1922 Evershed also discovered under conditions of good visibility innumerable small displacements of lines equivalent to velocities of the order of a few tenths of a kilometre per second. Nearly fifty years later with better spectrographic and image resolution, extensions of this early discovery have added much information on wave phenomena in the solar photosphere and chromosphere.

For thirty-eight years, between 1922 and 1960, the Directors at Kodaikanal were Royds, Narayan, and Das. The activity in solar physics continued unabated and work progressed on the lines of the early years. The highlights of this era were the discovery of the oxygen lines in emission in the chromosphere without the aid of an eclipse, that of the centre-limb variations of the hydrogen lines and their use to study the solar atmosphere, and the detailed study of the properties of the dark markings seen in H-alpha.

For studies of the physical properties of stars the observatory had limited instrumental resources. Nevertheless, some interesting results on comets and stellar spectra were obtained, proving that the men who use the instruments at any such institution are more important than the instruments. Soon after his arrival in 1907 Evershed discovered the ultraviolet tail bands in Comet Daniel that are now ascribed to CO^+. Evershed made numerous studies of the planet Venus and of Nova Aquilae 1918. And the high dispersion spectra of Sirius taken by him have had the highest dispersion values employed in stellar spectroscopy until recently.

ASTRONOMY IN THE PRINCELY STATES

Patronage to astronomical study by Indian rulers, lacking after the time of

Jai Singh, was resumed in the nineteenth century. The ruler of Oudh established an observatory at Lucknow around 1832. A 6-foot mural circle, an 8-foot transit, and an equatorial by Troughton and Simms formed the principal equipment. Wilcox assumed charge and made some observations at this observatory, but it was closed in 1849 following his death. The Maharaja of Travancore founded an observatory at Trivandrum in 1836. A transit instrument, two mural circles, an equatorial telescope, and magnetic and meteorological instruments formed the main equipment of the observatory. It was renowned chiefly for the magnetic observations made by Broun, its director from 1851 to 1865. His major discovery, now one of the fundamental principles of terrestrial magnetism, was that magnetic disturbances on the earth are not localized, but are world-wide phenomenon. Broun is also associated with the discovery of the relationship between solar disturbances and subsequent changes in the state of the earth's magnetism at recurrent intervals of 27 days. He also found that the magnetic disturbances proceed from particular heliocentric longitudes. The activity of the observatory was greatly reduced in 1865 soon after Broun's retirement, but this establishment continues to the present day.

Towards the last decade of the nineteenth century an observatory was started at Poona. Called the Maharaja Takhtasingji observatory, it commenced activity under the direction of Professor K. D. Naegamvala. A part of the nucleus of the funds that were needed for the starting of the observatory was provided by the Maharaja of Bhavnagar. This observatory had the largest telescope in the country, a 20-inch Grubb reflector. It also had several smaller instruments which were principally used for eclipse observations. The most important work done here has been the observations of the solar corona of 1898. The Naegamvala expedition to Jeur and the successful observation of the corona and its spectrum form the first complete Indian effort of its kind on record.

ASTRONOMICAL RESEARCH IN THE UNIVERSITIES

While there have been very limited efforts directly by Indian universities to foster astronomical research, it is noteworthy that some individuals from these institutions have made very substantial contributions to the general progress of theoretical astrophysics. At the top of the list stands the pioneering contributions of Professor Meghnad Saha. They form the foundation for interpretative stellar spectroscopy. Saha's ionization formula revolutionized astrophysics, for it enabled an understanding of the physical conditions in the stellar atmosphere. Saha's second important contribution was his conjecture of the gains that would accrue to astrophysics from a stratosphere observatory. This stimulating suggestion represents the earliest thinking in a field that has come of age in the space era. Contributions in theoretical astrophysics by

D. S. Kothari, S. Chandrasekhar, R. C. Majumdar, and A. C. Banerji and his students are also of great importance in this field of knowledge.

The Nizam of Hyderabad established the Nizamiah observatory in 1908 at its present location in Begumpet. This was prompted by the donation of two telescopes by Nawab Zaffar Jung Bahadur, one of the courtiers of the Nizam. The larger one was a 15-inch visual refractor which was mounted at Hyderabad in 1922. The observatory has been under the control of Osmania University since 1919. The smaller instrument is an 8-inch astrograph built by Cooke with which the observatory participated in the great international programme of the 'Carte-du-Ciel'. The zones photographed at Hyderabad cover the declination belts $+36°$ to $+39°$ and $-17°$ to $-23°$. Its first three directors, Chatwood, Pocock, and Bhaskaran, supervised the gigantic work of preparation of the astrographic star catalogue. Twelve catalogues comprising observations of 800,000 stars were published. The study of comets, variable stars, lunar occultations, and solar activity was also pursued at Hyderabad. The addition of a spectroheliosope in the mid-thirties and a blink comparator extended the sphere of activity of the institution. Proper motion studies of stars in the Hyderabad astrographic zone were commenced. Since 1944, when Akbar Ali became the director of the observatory, a programme of double star measurements has formed an important addition to the activity. Akbar Ali's principal contriubtion was the subsequent acquisition of a 48-inch reflector.

TOTAL ECLIPSES OF THE SUN

Three total eclipses with paths of totality across India are memorable events in the history of astrophysics. The first one of 18 August 1868 created the discipline of solar physics, for at this eclipse the spectroscope was used for the first time to discover the gaseous nature of the prominences. The hydrogen emission lines seen in the prominence were so strong that the French astronomer Jansen reasoned they could be seen without the eclipse. The next day at the eclipse observation site this speculation was proved to be correct, making it possible for daily surveys of prominences thereafter without the need of a total eclipse. There were several teams scattered over the path of totality for studying this vital eclipse. The Madras observatory had two teams, one at Wanarpati and the other at Masulipatam. Clouds at Wanarpati interfered with the success of the expedition. At Masulipatam Pogson detected the hydrogen lines in emission, as had all the teams that had a programme of observation with the spectroscope. They also saw a bright yellow line near the position of the D lines of sodium. The line originated from a hitherto unknown element, later termed helium after the source of its earliest detection.

The eclipse of 12 December 1871 had a path of totality passing over Ootacamund and Pudukotai near the southern tip of the country. Jansen at this eclipse

reported the discovery of dark absorption lines in the coronal spectrum. This was the occasion when what we now term the F-corona was first seen.

On 6 June 1872 an annular eclipse was visible at Madras. Examining the region close to the moon's limb, Pogson found that the bright chromospheric spectrum flashed out for a short duration on the formation and again at the breaking up of the annulus. This is the first observation on record of viewing the flash spectrum at an annular eclipse.

The next important eclipse in the Indian region was the well-observed one of 22 January 1898. Numerous expeditions from different countries were scattered all along the path of totality from Ratnagiri to Sahdol in former Vindhya Pradesh. The Kodaikanal observatory instruments were at Sahdol and a fine series of white light photographs of different scale was obtained. Naegamvala organized a very comprehensive study of both the chromospheric spectrum and the corona at Jeur. The report of this successful expedition indicates the great care and thoroughness that went into its planning.

The Kodaikanal observatory sent out an expedition in 1922 to Australia to measure the deflection of starlight in the sun's gravitational field, an important aspect of Einstein's theory of relativity that could be experimentally verified. The expedition was a total failure, a result of dependence on equipment of bad workmanship taken on loan that even Evershed's wizardry could not rectify. Royds was deputed to the eclipses of 1929 in Siam and 1936 in Japan.

ROLE OF AMATEURS IN INDIA

Astronomy is a subject where activity by amateurs has often led to significant contributions. While such efforts in India have not been on the same scale as in western countries, they have nevertheless played an important role. The earliest of such activity on Indian soil in recent times can be ascribed to Jesuit priests. The first recorded use of a telescope is by Father Richaud at Pondicherry who in December 1689 discovered a comet and also that Alpha-Centauri was a double star, the fifth such object to be known at the time. Through most of the nineteenth century there were sporadic efforts of amateurs at observing solar eclipses and rare events like the transit of Venus. Nawab Zaffar Jung's interest in astronomy led him to acquire a whole array of telescopes, which later formed the principal instrumentation of the Nizamiah observatory. At Vizagapatam A. V. Narsing Rao with a 6-inch telescope made observations of the transit of Venus and Mercury as well as of many bright comets.

The introduction of celestial photography ushered in a new era in the discovery of variable stars. Numerous variables were discovered, and preliminary efforts indicated from the light curve the nature of the light variation. The class of long-period variables was particularly well suited for amateur studies

with small telescopes, since a large number of individuals observing a chosen set of three to four hundred such stars could ensure good continuity of observation for the light curve derivation. The novae and cataclysmic variables came under such scrutiny, as a result of which we have continuous light curves of most of these stars available since the first decade of this century. The pioneer of such study in India was R. G. Chandra of Bengal, who from 1919 until the late forties was a regular contributor each month to the American Association of Variable Star Observers (AAVSO) with its headquarters at Harvard observatory. Chandra's earlier observations were made with a 3-inch refractor owned by him. He was later loaned a splendid 6-inch Clark refractor by AAVSO to extend his observations to the fainter stars. Another amateur who came on the scene in 1927 was M. K. Bappu of Hyderabad. He contributed thousands of observations regularly to AAVSO and the Variable Star Section of the British Astronomical Association.

A sphere of endeavour particularly suited for study by amateurs has been the visual observations of meteors. It is only in recent years that photography by very fast cameras and radar-echo studies have been the principal means of acquiring information on these objects. In the earlier epoch the visual observer's information gave us all the statistical data on meteor showers and radiants. The Indian observer most prolific in making these observations was M.A.R. Khan of Hyderabad. Khan's observations were contributed to the American Meteor Society, and for many years he was their outstanding observer.

Amateur activity is generally fostered by astronomical societies formed by amateur groups. These have a considerable impact on the growth of astronomy. Efforts at organizing such a group led to the formation of the Astronomical Society of India in 1910. The Society functioned for over a decade on the lines of the British Astronomical Association with different sections for the study of variable stars, meteors, and the moon. It published a journal and had a few telescopes of its own used by the members for carrying out observations of interest. One of the members who functioned as Director of the Variable Star Section of the Society was C. V. Raman, who later discovered the well-known effect in optics named after him.

One of the most interesting amateur efforts encouraged by societies has been the grinding of telescope mirrors, and in this regard the Astronomical Society of India was no exception. Its journal records several accounts by members of the procedures they adopted for grinding by hand mirrors up to sixteen inches in aperture. The largest Indian-made aperture paraboloid prior to 1947 was that of H. P. Waran of Madras who used a grinding machine fabricated by him for the purpose. The mirror with an aperture of twenty-four inches was the primary of a reflecting telescope that could not be completed by him due to paucity of funds.

POST-INDEPENDENCE DEVELOPMENT

A committee appointed by the Government of India, with M. N. Saha as chairman, examined in 1945 a plan for the development of astronomical research and teaching at the existing observatories and in the universities. The recommendations made by this committee included (i) establishment in North India of an astronomical observatory with a telescope of large aperture; (ii) extension of facilities at the Kodaikanal observatory by making available a coronagraph, solar tower telescope, large-aperture Schmidt telescope, and a laboratory for solar terrestrial studies; (iii) establishment of a naval observatory and a nautical almanac section; and (iv) introduction of post-graduate teaching in astronomy and astrophysics at the universities of Delhi, Aligarh, and Banaras, where observatories with 15-inch-aperture telescopes were to be provided. Much of the committee's recommendations, especially in so far as the Kodaikanal observatory is concerned, has been implemented.

One of the most important developments in the post-independence period is the expansion of observational facilities in astronomy in the country. Apart from the modern telescope facility at Kavalur, special mention may be made of a large telescope with a diameter of about ninety-four inches, work on which is almost complete. 'The cylindrical radio telescope at Ooty and low frequency array telescope are among the most powerful of their types in the world today. Considerable advancement in the instrumentation for space astronomy has also been achieved.'[1]

[1] *Science in India: A Changing Profile*, ed. S. K. Mukerji and B. V. Subbarayappa (Indian National Science Academy, New Delhi, 1984), p. 76.

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PHYSICS

THE beginning of modern Indian physics may be dated from the sixties of the nineteenth century when Captain J. P. Basevi and his colleagues of the Trigonometrical Survey of India carried out an extensive survey of the gravity anomalies in the region of the Himalayan mountains. The explanation of their discovery of the low gravitational pull of the Himalayas in spite of its large size led to a new picture of the earth in which the interior is a thick, hot, viscous liquid, something like pitch. The crust of the earth, the land masses, some fifty miles thick, floats on this viscous sea. The lightest parts float high, while the heavier parts are low. For example, ice being almost as heavy as water floats with only a small portion of it above the water, but cork being extremely light will stand up high above the water while floating. This type of behaviour of the earth's crust has been found to be an extremely fruitful idea in understanding the behaviour, nature, and movement of the land masses of the earth.

Physics in the conventional sense started in India with the pioneering work of Jagadish Chandra Bose. His original investigations in physics date from 1895 when, as a professor of the Presidency College, Calcutta, he carried out a number of remarkable investigations on the generation of extremely short electric or radio waves having a wavelength of the order of a few millimetres and studied their properties. He showed that these radio waves are very similar to visible light waves and that these radio waves obey the laws of reflection, refraction, polarization, and double-refraction in a similar fashion as ordinary visible light. It is interesting to note that these very short radio waves generated by Jagadish Chandra Bose are very similar to those now used in radar which enable aeroplanes and ships to locate and detect obstacles and objects in front of them even in fog or through clouds. Professor D. N. Mallick of the Presidency College, another pioneer worker, investigated electrical discharges in tubes filled with gas. Later, interest in work on electrical discharges through gases diminished. The subject has now assumed importance not only because of useful inventions such as the fluorescent light in our homes but also because of its application to the physics of the generation (plasma) of extremely high temperatures and of nuclear power in the laboratory. However, these instances of research work in physics in the closing years of the nineteenth century and the early years of the present can be looked upon as precursors of wider scientific activity that started mainly in the city of Calcutta during World War I and have been continually expanding throughout the country ever since.

In this connection, two great names will always be remembered: Dr Mahendralal Sircar and Sir Asutosh Mookerjee. Both of them had the vision to recognize the importance of science in the future of our country and the need for encouraging and initiating students of science into the field of research. Dr Mahendralal Sircar, an M. D. of the Calcutta Medical College, founded the Indian Association for the Cultivation of Science in 1876 with the intention of popularizing science and encouraging research. The Association gave great impetus to research in physics as it provided the opportunity and facilities for work, among others, to a great genius, Sir C.V. Raman, as early as in 1907, several years before he joined the Calcutta University College of Science which, established in 1916 through the efforts of Sir Asutosh with magnificent endowments from Tarak Nath Palit and Rashbehari Ghosh, can equally claim to be a pioneer institution devoted to research in physical sciences. Raman was associated with both the organizations in Calcutta during his many years in this city. He was a pioneer in research on optical phenomena, which eventually led in 1928 to the discovery of the effect that now bears his name and won him the Nobel prize in 1930. Although Raman had started working on some aspects of diffraction of light at the Indian Association for the Cultivation of Science as early as in 1911, it was really around 1914-15 that he began devoting all his energies to physics. With his appointment as Palit Professor of Physics at the Calcutta University College of Science, Raman led a group of young research workers in both these organizations, who conducted research under his leadership on various optical phenomena. The names of those young and enthusiastic pioneers read like an honour roll of physics in the country. Among them S. K. Mitra, K. S. Krishnan, K. R. Ramanathan, K. R. Rao, S. Bhagavantham, S. S. Bhatnagar, S. C. Sircar, B. B. Roy, P. N. Ghosh, N. K. Sethi, I. Rama Krishna Rao, and S. K. Banerji are now famous for their contributions in various fields of physics. All of them worked with Raman at one stage or the other in perhaps the most vital decade of Indian physics between 1915 and 1925.

Three other important names, M. N. Saha, D. M. Bose, and S. N. Bose, also belong to this decade. Saha was a leading theoretical and astrophysical researcher. His now famous equation of thermal ionization provided the clue to the measurement of the temperature of stars. He started his career in Calcutta and then joined Allahabad University where he organized a band of workers in theoretical and experimental physics. His work on ionization of gases and its various applications inspired many brilliant workers of the succeeding decade. Amongst them D. S. Kothari, R. C. Majumdar, B. N. Srivastava, and P. K. Kichlu have in turn inspired many students in physical research. Saha in the latter part of his career was keenly interested in nuclear physics. In 1939, with Calcutta again as his centre of work, he

inspired a group of workers in nuclear physics and founded the Institute of Nuclear Physics of which he was the first Director. This Institute now bears his name. D. M. Bose started his researches in Germany in 1915 on radioactive radiations. On his return to Calcutta he continued his investigations in connected subjects and subsequently also in magnetism. He later worked on cosmic rays and inspired the study of cosmic radiation at Bose Institute where he served as Director for many years. Actually cosmic ray work started in India in 1926 when the American scientist A. H. Compton, Nobel prize winner and cosmic ray physicist, came to Lahore and carried out some experiments. One of his students, P. S. Gill, returned to India in 1939 and built up a school of cosmic ray physics at Aligarh. His group also worked in the field of nuclear physics in collaboration with H. Hans and others. S. N. Bose deduced Planck's Law of Black-body radiation by considering directly the statistics of an assembly of photons in a six-dimensional phase space according to a method later extended by Einstein to an assembly of material particles. Bose's work introduced a new method in quantum statistics which came to be known as Bose-Einstein Statistics. This was responsible for stimulating the work of Fermi and Dirac on the alternative statistics which apply to most elementary material particles (Fermi-Dirac Statistics). Another great figure in theoretical physics, S. Chandrasekhar, started work in India in 1927 and subsequently spent most of his time in England and America. His researches on the conditions existing in stars were applied by him and his co-workers to the problems of generating thermonuclear power. His significant contributions to stellar astrophysics and other areas won him several awards including the Nobel prize for physics in 1983.

S. K. Mitra, founder and Head of the Department of Radiophysics and Electronics of Calcutta University, was a pioneer in ionospheric research in India. He developed interest in the subject in 1928 and was responsible for establishing a school of ionospheric research. Some of the researchers of this school have become important physicists in their own right such as H. Rakshit, J. N. Bhar, A. P. Mitra, S. Boral, S. Deb, and J. S. Chatterjee. Many of them have established their own schools of studies.

K. S. Krishnan, who later became Director of the National Physical Laboratory, started as a collaborator of Raman but gradually shifted his interest to magnetic properties of crystals. He inspired many young physicists in their study of magnetism. Amongst them are A. Bose and K. R. Ramanathan.

The period between 1925 and 1945 witnessed expansion and consolidation of the work that had been started earlier. Centres of research grew up mostly around the physics departments of various universities. The Meteorological Department of the Government of India also played an important role in

physical research. Ramanathan did most of his work on the upper atmosphere as a member of this Department. Others who collaborated in this field were N. K. Sur, G. Chatterji, and Ramakrishnan. S. K. Banerji, S. L. Malurkar, and L. A. Ramdas also investigated the conditions of atmosphere and weather. A. K. Das, also of the Meteorological Department, first started around 1935 spectroscopic investigations on the night sky and the sun, and devoted himself to the development of the solar observatory at Kodaikanal. He was later in charge of the Nizamiah observatory at Hyderabad where he was responsible for installing India's biggest telescope (a 50-inch reflector).

After Compton's work on cosmic rays in 1926 research in this field suffered a set-back in this country. H. J. Bhabha and D. M. Bose were mainly responsible for its revival. Bhabha joined the Indian Institute of Science at Bangalore after initial work in England in the early 1930s and began his study of the theoretical problems of cosmic rays. He realized the possibility of experimental work in this field in India since the geomagnetic equator passes through the country, and organized experimental work in cosmic rays with the help of other scientists. He later moved to Bombay as Director of the Tata Institute of Fundamental Research which he helped to found. He inspired a lively group in theoretical and experimental studies of cosmic rays and fundamental particles. The experimental group at the Tata Institute led by an able emigré physicist, B. Peters, carried out systematic investigations on cosmic rays. After the departure of Peters this work was taken up by a group of able young physicists led by M. G. K. Menon, Shreekantan, Yash Pal, S. Biswas, and others.

The post-war years saw a great expansion of physical research. R. S. Krishnan and his colleagues at Bangalore worked on the crystal state of matter. G. Ramachandran, theoretical physicist at Madras, made important contributions on the structure of proteins. A. Ramakrishnan also built up at Madras a school of theoretical studies in particle physics. S. Ramaseshan, an experimental physicist, and his colleagues at Bangalore worked on crystal and solid state physics. Jnanananda set up a nuclear physics laboratory and S. Mahadevan a geophysics laboratory at Waltair. A. Verma, once Director of the National Physical Laboratory, worked on the solid state of matter. Others who contributed significantly were K. Banerji in crystal studies with X-rays; S. N. Ghosh and Krishnaji in microwaves at Allahabad; and P. Venkateswaralu in microwaves at Aligarh.

The Indian Association for the Cultivation of Science at Jadavpur, Bose Institute, and the Saha Institute of Nuclear Physics in Calcutta promoted work on solid state physics, thermal diffusion, nuclear physics, and theoretical physics. Among the numerous researchers who created small schools of workers, mention may be made of B. N. Srivastava, A. Bose, A. K.

Saha, D. N. Kundu, M. S. Sinha, J. N. Bhar, S. D. Chatterjee, M. K. Banerjee, and T. N. Pradhan.

Under K. Ramanathan and V. Sarabhai a group at Ahmedabad studied the upper atmosphere and cosmic rays. A rocket launching station at Thumba in Kerala was set up in the early 1960s, and investigations on the upper atmosphere and the exosphere, the space just beyond the atmosphere, were undertaken with the help of rockets leading to the launching of *Aryabhata* in 1975 followed by *Bhaskara* in 1979 and *Apple* in the early 1980s. The study of middle and upper atmosphere by groups in the National Physical Laboratory under A. Mitra and in the Physical Research Laboratory under D. Lal flourished. Lal and Ramanathan contributed substantially to the development of (i) atmospheric and cosmic radiation researches and their use for geophysical researches, and (ii) paleocosmic radiation studies, cosmic radiation work of a more classical variety. M. Sinha and his group at Bose Institute and later at Durgapur used Wilson Cloud Chamber techniques with good effect. Shreekantan and M. G. K. Menon worked on neutrino fluxes in cosmic rays and set up an elaborate experiment in the Kolar gold mine which is still proceeding. At Delhi a centre of research, set up under D. S. Kothari, continued to make progress and expand under Majumdar, Auluck, A. N. Mitra, and others.

The Government of India created in 1954 a department to look after and develop atomic energy in this country. Under H. J. Bhabha this department sponsored nuclear physics research as well as organized atomic energy work. Many able, young scientists were associated with the research establishments of the department, among whom mention may be made of H. N. Sethna in nuclear technology, K. Singvi in theoretical physics, M. G. K. Menon in astrophysics and cosmic ray physics, and Raja Ramanna in neutron physics. The department also supported research and research workers in nuclear physics and cosmic ray work at Delhi, Calcutta, Ahmedabad, and other places.

Starting with a swimming pool reactor in the 1950s, the Atomic Energy Centre, now called Bhabha Atomic Research Centre (BARC), developed several reactors for experimental research on materials and neutrons as also a nuclear power programme. Raja Ramanna, P. K. Iyengar, and others contributed largely to this effort. In Calcutta at the Saha Institute of Nuclear Physics and in more recent years at the Variable Energy Cyclotron Centre researches in nuclear physics with charged particles have been and are being carried out. Researches in solid state physics also were a substantial part of the effort at Calcutta by A. K. Saha, S. K. Mukherjee, A. P. Patro, P. N. Mukherjee, B. Basu, and others. A strong group in theoretical physics has been built up with M. K. Pal and others, mainly in nuclear physics. Other

groups such as T. Pradhan's in Bhuvaneswar in theory, G. N. Ramachandran's in protein structures, H. S. Hans's in experimental nuclear physics in Chandigarh, and Bhide's in Pune have also made significant contributions in physics.

A number of Indian students working in the United States have built up a reputation for themselves in the fields of theoretical particle physics and plasma-physics.

Physics in India established itself during the period 1915-25. It consolidated its position and physical research came to be a regular university activity during 1925-40. The post-war years have seen a great expansion in the research activities of the country. Research in physics is no longer a glass and sealing wax tinkering in a basement. It requires large resources in men, technology, and money. Its importance has also tremendously increased in this age of transistors, atomic energy, rockets, and nuclear power. Many Indian physicists feel that in spite of the growth in research activity during recent years, it is not expanding fast enough. Research is not attracting the best talent capable of making it far more exciting and productive. Some of the outstanding physicists like Chandrasekhar and Narlikar seem to be at their best when working in foreign universities. The standards of research are international; and the speed of accomplishment that is demanded is tremendous. To keep abreast, not to say forge ahead, requires resources not only of talent and money but of technology and stimulation as well. Unfortunately in our country physical research has remained in isolation from technology. There is very little of mutual stimulation which would bring live problems into the physical laboratory.

In recent years interdisciplinary branches of study have developed in a number of areas. Of these, biophysics, geophysics, and chemical physics deserve special mention. In geophysics Hari Narain of the National Geophysical Laboratory and P. K. Bhattacharya, who died prematurely in an accident, were promising workers, having initiated small schools of research in the area of geophysics. Biophysics attracted a number of research workers such as Gopala Iyengar and Srinivasan of Bombay; Guha of Varanasi; and N. N. Das Gupta, N. N. Saha, and R. Poddar of Calcutta. In chemical physics, studies of surfaces and of long-chain polymers by Palit at the Indian Association for the Cultivation of Science and others, have been significant areas of interest.

To a large extent physics has still to create a machinery for bridging the gap that exists today in our country between physics research in the laboratory and technology in the industries. To an even greater extent Indian physics has still to create the atmosphere of intellectual stimulation that will feed the existing talent in the country and make them creative. These are the

two major challenges for physics in our country. Indian physicists can, however, look back with satisfaction that they have contributed significantly to the international pool of knowledge during the last fifty years or more. The challenges of today will doubtless carry the new generations of physicists much further. The symptoms are in evidence.

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CHEMISTRY

INTRODUCTION

CHEMISTRY is a major branch of science extensive in scope. It is essentially concerned with the composition and structure of matter, and uses both analytical and synthetical methods. Vast expansion in chemical knowledge has taken place all through history and particularly in recent times largely due to its application to the primary needs of man. The subject is changing fast in its methods and expressions. In spite of large expansion, there has been simplification also in that our ideas about the subject are becoming more definite and clear, because the vital secrets of chemical phenomena are better understood.

Knowledge in the absolute sense is most ancient; so is chemistry as a science. It has been in operation ever since matter and energy came into existence. By their interaction changes take place continually and on a large scale. These changes may be marked and spectacular when high temperatures are involved or may be slow and yet sure at comparatively low temperatures. But chemical changes are subtle. They are not related to changes in form and size, but in subtle qualities and hence could not be clearly understood in the early periods of history and could not be explained for a long time. Real progress in chemical knowledge has taken place mainly during the past two centuries, though chemistry is very ancient.

One of the primary chemical discoveries was that of fire; it was so important for man that fire was worshipped as God. Later it was called combustion; the explanation of this phenomenon as oxidation involving oxygen of the air was made only about two centuries back by Lavoisier in Paris though combustion has been used most widely from the dawn of history. Another great and very early step was the working of metals, particularly preparing them from their ores and using them. This involves a typical chemical reaction called reduction. Conversion of elements into compounds and compounds into elements was therefore known and used from time immemorial, but chemical understanding of the methods became possible only compratively recently.

BACKGROUND HISTORY

In India some of the special features of chemistry seem to have been understood much earlier than in other countries. Science in the strict sense was not dissociated from philosophy and they had close interaction even from remote times. The atomic nature of matter and the union of atoms to

form larger aggregations or molecules, both homogeneous and heterogeneous, constituted the fundamental postulates used by Indian thinkers for the explanation of the nature of the universe and its evolution. But they were only brilliant speculations and lacked experimental basis which could be provided only much later in Europe and which led to the atomic theory of Dalton.

Much of ancient and medieval chemistry has been generally called alchemy, the precursor of modern chemistry. Alchemy was also closely associated with philosophical thought and alchemical practices in India were looked upon as aids to divine union. In other civilizations the twin objectives of alchemy were: (1) discovery of the philosophers' stone which is capable of converting base metals into gold; (2) discovery of the elixir of life. In both of them the essential feature was change from one into another. In India the emphasis seems to have been more on the second aspect. Ancient Indian chemists are credited as being the earliest to introduce mineral preparations as medicine. Mention may be made in this connection of the use of mercury compounds, mercuric sulphide and chloride. So much importance was given to their use that the science of chemistry has been called *rasāyana*, *rasa* meaning mercury. Indian alchemists had to their credit great achievements in metallurgy. Copper and bronze were in use from the ancient days of the Indus valley civilization. The working of metals was a widely practised art in ancient and medieval India.

ADVENT OF MODERN CHEMISTRY

After the medieval period the study of chemistry in India suffered a set-back on account of various reasons. In the West modern chemistry was placed on a solid foundation from the early seventeenth century by systematic experimental study of natural phenomena and materials such as air, carbon dioxide, and water and systematic interpretation of observed facts. Robert Boyle, Lavoisier, and others initiated the experimental school which gave the right direction to chemistry. In India this experimental approach to science was lacking. Modern chemistry, therefore, did not result from indigenous development, but had to be introduced by visitors from Europe or officers of European powers in the early stages, and later by European scholars and scientists employed in India. From the advent of the Portuguese traders in the sixteenth and seventeenth centuries followed by the Dutch, French, and British, a steady flow of Jesuit missionaries, European medical men, and naturalists took place into the coastal areas of India and even into interior places like Delhi. In the nineteenth century this became more pronounced and consisted largely of army medical men and engineers who had received training in European institutions and laboratories. They were responsible for introducing literature on science and technology and scientific apparatuses,

chemicals, and the technical know-how. They also helped in the organization of some of the important scientific institutions and societies in India.

Prior to the 1860s chemistry used to be taught in medical colleges as a help to the study of medicine. It was only after the major universities were founded around 1860 that chemistry was slowly introduced as a special subject of study. Even then it was a part of liberal education and did not, therefore, assume importance until teaching and research in chemistry were provided by major government colleges like the Presidency Colleges in Calcutta and Madras and the Institute of Science in Bombay. The Indian Association for the Cultivation of Science, founded by Dr Mahendralal Sircar in 1876, also had arrangements for courses of lectures in chemistry. 'In the eighties of the last century chemistry had made gigantic strides and it was realized that the mere delivery of elementary courses of lectures would not be adequate to cope with the requirements and that special arrangements must be made for practical and laboratory teaching.'[1]

The foundations for the development of chemistry in India were laid by the pioneering work of Acharya Prafulla Chandra Ray whose first great contribution to the subject in the 1890s was connected with mercury, traditionally associated with Indian medicine. It was the preparation of a mercury compound, the unstable and till then unknown mercurous nitrite, and the study of its properties. Later he specialized in the chemistry of these unstable nitrites and could even vaporize and determine the vapour density of ammonium nitrate which decomposes readily into nitrogen and water. As in many other national activities, Ray exhibited patriotic fervour in his chemical research and teaching as also in organizing chemical industries. Inspired by his direct experience abroad of the application of the results of laboratory researches in the field of industries or national progress, Ray started at his personal residence (91 Upper Circular Road now called Acharya Prafulla Chandra Ray Road) a small chemical factory in 1892. The Bengal Chemical and Pharmaceutical Works Ltd., established in 1900, had its beginnings in that chemical factory.

Under the able guidance of Ray who joined the Presidency College as professor in July 1889, facilities for the study of and research in chemistry in this college were gradually expanded. In 1894 a new building was commissioned which formed the centre of chemical research work. Gradually a great volume of original work in pure as well as applied chemistry was done not only at the Presidency College in Calcutta but also in various universities and research laboratories in the country. Calcutta University, on the initiative of its Vice-Chancellor, Sir Asutosh Mookerjee, effected a breakthrough by opening a College of Science in 1916. About the same time

[1] P. C. Ray, *Autobiography of a Bengali Chemist* (Calcutta, 1958), p. 63.

the Indian Institute of Science started functioning as an important research institute at Bangalore in the south. The Indian Science Congress was soon inaugurated. It provided a forum for scientific discussion and stimulated research. In the early twenties of this century the Indian Chemical Society was also formed and it conducted a regular journal in chemistry publishing original papers. Further development took place when unitary universities like the Banaras (1916), Lucknow (1918), and Annamalai (1929) Universities came into existence. The research responsibility of these universities was accepted.

After independence the popular governments at the Centre and in the States recognized the importance of science for national development and provided large budgets on both general and scientific education. New universities, colleges, and research institutions were set up all over the country with facilities for studies in, and research into, the sciences in general and chemistry in particular. A large number of scholars were sent abroad for training. In addition, a number of national and government laboratories devoted to research in applied chemistry connected with various agricultural commodities and industry came into existence. This resulted in notable achievements in the various branches of chemistry. It is not possible within the space of an article to make exhaustive reference to such achievements. Some of the salient among them are, however, enumerated below.

CHEMISTRY OF NATURAL PRODUCTS

The natural wealth of India drew the attention of early scientists like Dymock, Roxburgh, and Watt, who worked in this country and left very useful records of her plant resources, particularly their habitats and well-known uses. Early studies in India's plant chemistry were, however, made in German and British laboratories. Baeyer's classical study of the chemistry of indigo led to the establishment of the synthetic indigo industry in Germany. A. G. Perkin did pioneering work on the vegetable mordant dyestuffs known as flavonoids. The names of W. H. Perkin (Junior) and Robert Robinson are always mentioned in the study of the alkaloidal components of famous drugs like opium and nux-vomica.

Terpenoids: The earliest major chemical research in India on natural products was done by Sir John Simonsen, who worked for a number of years in the Presidency College, Madras; in the Forest Research Institute, Dehra Dun; and finally in the Indian Institute of Science, Bangalore. He had studied earlier the sweet-smelling essential oils of some Indian grasses. More important was his work on Indian turpentine. He made the discovery of new and unstable types of compounds called carenes. The major group into which these chemical substances fall has been named terpenoids. He left behind a number

of trained workers and a tradition for the study of this branch of chemistry. It was successfully and ably followed up not only in Bangalore but also in Pune and other places.

Alkaloids: This is the group name for a number of chemical compounds containing nitrogen, having basic nature, and possessing medicinal properties. Interest in alkaloid chemistry arose from their presence in well-known vegetable drugs like opium, nux-vomica, and cinchona. After the first World War the study of Indian plant drugs assumed great importance and pharmocological and clinical researches were undertaken in the School of Tropical Medicine in Calcutta. Chemical studies on the isolation, properties, and the constitution of some alkaloids were also carried out. This work continues to grow in this institution. A similar drug unit was opened in Madras. Eventually studies of this group of chemical compounds have developed to a considerable extent in Madras and Calcutta, and the university and college laboratories have been playing an increasingly prominent role in this respect. Some major studies were made in the laboratories of the Tibbia College at Delhi for a number of years, especially on the alkaloids of *Rauwolfia serpentina* and of *Holarrhena antidysenterica,* which are famous drugs. Thus a large number of alkaloids have been studied in detail. The role of the Central Drug Research Institute at Lucknow may be specially mentioned in this connection.

Flavonoid Colouring Matters: Many flowers, fruits, leaves, barks, and roots have been in use from time immemorial as mordant dyes. They are so called because mordants like aluminium, tin, and chromium salts are used for fixing their colours to the fabrics. Their chemical components are called flavonoids, since in their molecules the primary structure that is responsible for colour is named flavone. This flavone itself occurs as a yellow powder on the plants of the *Primula* species. The flavonoids have a number of phenolic hydroxyl groups. Therefore they are also called polyphenols. To this group belong the anthocyanins, which constitute the bright red and blue colouring matter of flowers, but they are not suitable for dyeing. After the advent of synthetic dyestuffs, also called coal tar dyes, the dye importance of flavonoids ceased, but their importance in other directions has increased. For example, many of these have vitamin P properties preserving the healthy condition of blood capillaries. They are also responsible for taste and antioxidant properties in food and are important in plant physiology and classification. Some of them have hormonal properties. Flavonoids are very large in number and belong to a number of structural groups. Further, they occur frequently in combination with sugars forming numerous flavonoid glycosides. From the thirties of this century considerable work on the flavonoids has been done in Indian universities, especially at Waltair, Delhi, and Bombay. The study

of flavonoids has assumed major importance also in many other countries.

Lichen Products: Most of us are familiar with the marvellous development of antibiotics in recent years. These are products of fungi and similar micro-organisms and are therefore called fungal products. In the post-war years there was a spurt of activity all over the world on the study of fungal products as well as related ones. In this connection a group of plants called lichens becomes important. They consititute an interesting symbiosis of algae and fungi and hence are capable of producing antibiotics. The lichens are highly specialized plants and their chemical components are unique in many respects. Earlier studies in this field were made in Germany, but Indian chemists have made special contributions along with those of Japan. It may be mentioned that during the past several centuries useful dyes and food colours have been obtained from lichens. Even now litmus is prepared from only this natural source. For a long time some of them have been used for poisoning wolves and some as antibiotics in the crude state. Usnic acid from lichens in combination with several other compounds has been found to be a remedy for tuberculosis.

Insecticides and Rotenoids: India being an agricultural country, there was interest in the use of insecticides to control plant pests. But most of the earlier scientific study was made in European countries, the United States, and Japan. One of the great achievements of science of the present century is the discovery and development of what are known as selective insecticides. They are selective in the sense that they are toxic to insects but not to human beings or animals. Under this category come the roots of derris species and compounds called rotenoids obtained from them. During the last war the extremely rapid advance of the Japanese and their occupation of Indonesia and Malaya cut off all supplies of derris roots which constituted important insecticides. Alternative sources had to be found. A survey of Indian derris roots and their chemical study were therefore started as an urgent measure. As a result, schools of workers on plant insecticides grew up in Waltair, Delhi, and Osmania Universities. A large variety of novel chemical compounds were isolated and their chemical structures established. The synthesis of these compounds, particularly rotenoids, marked an important advance in chemistry. Further, the urge to know the relationship between the chemical constitution of a substance and its insecticidal properties provided stimulus for extensive experiments. This led to a new synthesis of simpler types having insecticidal properties.

Complex Natural Products: During the last war the supply of rubber was also similarly cut off. A number of latex-bearing plants were tried; but most of them yielded triterpenoids, and not rubber. While both are made up of the same building unit called isoprene, rubber is a linear polymer having its

characteristic elasticity whereas triterpenes are smaller in size having four or five rings in their moleucles. The study of triterpenoids has since attracted a great deal of attention, and these numerous and complex compounds obtained from barks, leaves, and other parts of plants have been widely investigated.

Many plant drugs owe their value to the presence of glycosides. They derive their name from the fact that they yield glucose or other kinds of sugar on hydrolysis with acids or enzymes; the non-sugar parts are responsible for their special properties. The most important of these are cardiac glycosides, so called because they are useful for heart diseases. Pioneering studies of these were originally made in Germany and Switzerland. India is rich in these drugs. Useful and important investigations have been done in Indian universities and other laboratories specially devoted to drug research. Particular mention should be made of the study of Indian squill and Thevetia, which are well-known drugs and poisons. The glycosides have steroid skeletons similar to those of sterols, e.g. cholesterol of brain and nerve tissues.

Saponins and sapogenins are related to triterpenoids and steroids. They are either poisonous or have medicinal values, and are used industrially as emulsifying agents and stabilizers of emulsions. Further, they can be made the basis for the synthesis of hormones. Wide survey has been made of this group, some of which are industrially exploited. Yams (*Dioscorea* species) and some species of *Solanum* are important for this purpose.

Wood Chemistry: Tropical woods have been highly valued as materials of construction. The heart-wood which is a dead tissue is the most valuable part. Good wood has to satisfy two important criteria: (1) it should withstand the attack of insects and micro-organisms and should therefore have insecticidal and antibiotic principles, and (2) it should withstand the attack (oxidizing effect) of the atmosphere and should therefore have antioxidants in it. The study of heart-woods has provided data of great interest on the special features of the components and their properties. Some of the woods provide useful dyes, some useful drugs, and many of them contain highly useful plastic materials.

Other New Fields of Development: During the earlier years of the development of chemistry the main interest lay in minerals and in discovering and studying new metals and non-metals and their compounds. This was called inorganic chemistry. Later new branches of organic chemistry and physical chemistry developed rapidly and interest in inorganic chemistry waned. Recently, however, there has been a revival largely due to the great importance of atomic energy and atomic minerals. The barrier between organic and inorganic chemistry has been breaking down. Considerable work is being done on metallo-organic complexes. Many of them have

interesting properties and are also highly useful as analytical reagents and catalysts.

Radiation chemistry, in relation to atomic minerals and energy, and photochemistry, concerned with the chemical action of light, are two other fields of development in the study of chemistry. A major branch of chemistry, developed in the closing years of the nineteenth century and early years of this century, is physical chemistry dealing with precise measurements of quantities of mass and energy in the study of phenomena in both the inorganic and organic fields. A theme which has been popular for a long time is colloid and surface chemistry. Colloids represent a state of matter which is in between the subtle molecules and gross solids. It is sometimes called the fourth state of matter. Much work was done in the twenties and thirties of this century by leading Indian chemists and the interest continues. Electrochemistry dealing with the application of electricity to chemical reactions and processes is another major branch of physical chemistry.

GROWTH OF APPLIED CHEMISTRY

With the progress of the study of chemistry in India there have emerged votaries of pure science who feel that pure science is an end in itself and that its high intellectual value is all that matters. According to them, experiments are to be done in order to study chemical phenomena and to develop new ideas which would lead to new experiments. Another school stresses the applied aspects of the study of chemistry and argues that it should have major human value and prove helpful to society. The study of chemistry in this country has proceeded on both the lines. The universities in general and some of the research institutes in particular like the Tata Institute of Fundamental Research (Bombay), the Indian Institute of Science (Bangalore), and the National Chemical Laboratory (Pune) have specialized mainly in fundamental research, while some institutions have grown to study the major natural resources of the country with a view to their better utilization. Mention may in this connection be made of the studies in applied chemistry in such fields as those of textiles (dealing with cotton, jute, etc.), synthetic dyestuffs, leather, coal, sugar, cement, tea, coffee, drugs, food, and glass and ceramics. The Central Glass and Ceramics Research Institute in Calcutta has developed glass technology to a very high international level. Similarly, the Central Drug Research Institute, Lucknow; the Textile Industries Research Association, Ahmedabad; the Indian Jute Industries Research Association, Calcutta; the Central Food Technological Research Institute, Mysore; the Central Leather Research Institute, Madras (with extension centres at Bombay, Calcutta, Kanpur, etc.); the Cement Research Institute of India, Delhi; the Central Electrochemical Research Institute, Karaikudi; the Central Salt and

Marine Research Institute, Bhavnagar; the Central Fuel Research Institute, Dhanbad; and the Indian Institute of Experimental Medicine, Calcutta, are doing important work in their respective fields. The chemistry of food and nutrition has come up to a high standard, the study of food toxins being a major field of research in India. Remarkable expansion of the pharmaceutical industry has taken place all over the country since the establishment of the Bengal Chemical and Pharmaceutical Works in Calcutta by P. C. Ray in 1900.

The present age, described as one of plastics and polymers, has seen great developments in the synthetic field. Natural compounds of this type have been known and used from ancient days. Many of these have held the field in competition with synthetics. One such is lac resin which is an insect product. Its chemical study has led to the development of lac technology. The Indian Lac Research Institute, Ranchi—the only one of its kind in the world—has done significant work in this respect. The post-independence period has witnessed great proliferation of the chemical industry under the five-year plans. This has resulted in the bulk production of basic chemicals, petrochemicals, insecticides, commercial explosives, dyestuffs, etc., making for self-sufficiency in many sectors.

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BOTANY

IN a modern sense botanical activity started in India a little over one hundred years ago. During the nineteenth century botany in this country was largely confined to the exploration, collection, and identification of plants. Other branches gradually emerged at the turn of the twentieth century. Morphology constituted the first stage of development and the earlier years were marked by contributions relating to mycology, anatomy, cytology, and ecology. Then pathology, physiology, and genetics followed. Recent years have witnessed rapid strides in all disciplines including microbiology, embryology, palynology, palaeobotany, and plant breeding.

TAXONOMY

Plant taxonomy, the oldest of botanical disciplines, developed in India even in the Vedic period. Later the Portuguese and Dutch, attracted by the vast potentialities of the country's vegetation, initiated the modern study of Indian plants. By and by the exploratory phase entered into the systematic phasc and the investigations carried out by British army, medical, and forest officers resulted in the publication of several floras. The appearance of Hooker's masterpiece, *Flora of British India*, in the last decade of the nineteenth century gave a great fillip to taxonomic work. Since then numerous books, catalogues, papers, and notes dealing with the vegetation of various Provinces and districts have come to light. Excellent reviews of the early history have been written by Agharkar, Burkill, and Biswas. Modern works have been chronicled by Santapau. Among provincial floras, mention may be made of Cooke's *Flora of the Presidency of Bombay* (1901-08), Prain's *Bengal Plants* (1903), Duthie's *Flora of the Upper Gangetic Plain* (1902-22), Gamble and Fisher's *Flora of the Presidency of Madras* (1915-25), and Haines's *The Botany of Bihar and Orissa* (1921-25). For collectors of specimens from hill stations, Collett's *Flora Simlensis* (1902), Fyson's *Flora of the South Indian Hill Stations* (1915), and Blatter's *Beautiful Flowers of Kashmir* (1928) serve as constant companions. Important works on forest vegetation are *Forest Flora for the Punjab with Hazara and Delhi* (1918) by Parker, *Forest Flora of the Bombay Presidency and Sind* (1909-11) by Talbot, *Forest Flora of the Andaman Islands* (1923) by Parkinson, *Forest Flora for Kumaon* (1927) by Osmaston, and *Forest Flora of the Chakrata, Dehra Dun and Saharanpur Forest Divisions, United Provinces* (1928) by Kanjilal. Santapau's *Flora of Khandala* and *Flora of Saurashtra* as well as J. K. Maheshwari's *Flora of Delhi* have been based on modern lines.

The Forest Research Institute at Dehra Dun, the National Botanical Research Institute at Lucknow, the French Institute at Pondicherry, and the

Botanical Survey of India with its regional centres are the major organizations concerned with floristic and taxonomic studies in the country. Since the Botanical Survey was revived in 1954, useful floristic accounts of Jammu and Kashmir, Lahul, North Garhwal, Jodhpur Division, Sikkim, Andaman and Nicobar, Rampa and Gudem Ghats, and the Kameng, Siang, and Tirap districts of Arunachal Pradesh are available now. Interesting genera like *Eskemukerjea*, *Parakaempferia*, *Pauella*, *Pauia*, and *Seshagiria*, and more than seventy species are new to science. The Survey has also brought out a revised work on Bhutan orchids, *Cynodon*, *Derris*, *Rubia*, *Viscum*, etc., as well as publications on vegetation mapping and bioclimates in India and reprints of the old floras of different States. These contributions have created a great enthusiasm among Indian botanists to revise the State floras where they exist and to prepare new ones where they are wanting. The Botanical Survey is keen on implementing projects for the revision of families for the flora of India.

CRYPTOGAMIC BOTANY

Investigations on cryptogamic botany can be reviewed best under the following sections.

Algae: Before the twentieth century most of the contributions on Indian algae were by foreign botanists. Towards the first quarter of the present century four major centres of research on algae were developed—one each in Bengal (by Brühl and Biswas), Madras (by Iyengar), U. P. (by Bharadwaja), and Punjab (by Ghose). Other noteworthy workers included Randhawa and Allen. An officer of the ICS cadre, Randhawa performed creditable work in his spare time. Allen was also a civil servant, contributing to our knowledge of the Indian Charophytes.

Recently algal laboratories were set up in universities and research institutes in Udaipur, Bhavnagar, Bombay, Mandapam, Hyderabad, Allahabad, Kanpur, Lucknow, Delhi, Ranchi, and Cuttack. A series of monographs on Indian algae were published by the Indian Council of Agricultural Research (ICAR): *Cyanophyta* (1959) by Desikachary, *Zygnemaceae* (1959) by Randhawa, *Role of Blue-green Algae in Nitrogen Economy of Indian Agriculture* (1961) by R. N. Singh, *Charophyta* (1959) by B. P. Pal *et al.*, *Vaucheriaceae* (1962) and *The Cultivation of Algae* (1969) by Venkataraman, *Ulotrichales* (1964) by Ramanathan, *Phaeophyceae* (1966) by J. N. Misra, and *Chlorococcales* (1967) by Philipose.

R. N. Singh studied the limnological relations of inland waters with reference to water blooms as well as freshwater productivity and water pollution. He isolated several algae from rice fields and established nitrogen fixation by forms like *Aulosira fertilissima*. Venkataraman and his co-workers showed that artificial inoculation of high-yielding rice varieties with nitrogen-fixing blue-green algae pushed up grain production. Thivy and his collaborators

made valuable contributions on the economic utilization of seaweeds, particularly agar and algin-producing organisms.

Most of our knowledge of the genetics and biology of blue-green algae is based on work conducted at the Banaras school. R. N. Singh proved the procaryotic nature of the group and demonstrated nitrogen fixation by cell-free extracts from several species. Genetic recombinations have been reported in *Anacystis nidulans* and *Cylinarospermum majus*. It has been shown that blue-green algae provides an excellent model for the perusal of development and differentiation at a molecular level. An ultra-violet induced mutation in *Nostoc linckia* resulting in true branching and frequent heterocyst germination in *Gloeotrichia ghosei* have been obtained. A number of blue-green algal viruses, the 'Cyanophages', were isolated from India by R. N. Singh and P. K. Singh who recorded for the first time the transduction of streptomycin resistance and lysogeny with some of these viruses.

Mycology and Pathology: E. J. Butler, who arrived in this country at the turn of the century, will always be remembered for his pioneering work on fungi. He was the first to initiate and organize mycological and plant pathological research in India. His book, *Fungi and Diseases in Plants* (1918), is considered a classic in plant pathology, while Mundkar's *Fungi and Plant Disease* (1949) is a widely-used textbook. Thirumalachar made significant contributions to systematic mycology, his work comprising almost every class of fungi. Dasgupta and his group made an exhaustive contribution on the role of enzymes in plant diseases. Tandon and his students worked on the physiological aspects of fungi causing leaf spots and fruit diseases. The Madras school, led by Sadasivan, has devoted considerable attention to the physiology of the wilt disease. Besides Madras, there are active centres of research on mycology and plant pathology at the universities of Gauhati, Calcutta, Kalyani, Allahabad, Lucknow, Agra, Delhi, Rajasthan, and Punjab; agricultural colleges at Pune, Kanpur, and Coimbatore; Forest Research Institute at Dehra Dun; and the Indian Agricultural Research Institute (IARI), New Delhi.

Several monographs on Indian fungi have been put out by ICAR: *The Clavariaceae of India* (1961) by Thind, *Pythiaceous Fungi* (1962) by Rangaswami, *Indian Cerosporae* (1963) by Vasudeva, *Mucorales of India* (1968) by Tandon, *Indian Polyporaceae* (1971) by Bakshi, and *Hyphomycetes* (1971) by Subramanian.

In addition, Thind and his group recorded over seventy species of Myxomycetes from Mussoorie and other parts of northern India, several of which are new slime molds. A study of the life-cycle of *Stemonitis herbatica* has revealed that the haploid phase is of the complete flagellate type and the zygote is a product of isogamy.

Aquatic phycomycetes received scant attention from Indian students,

although Karling registered several fascinating forms from freshwater and marine environments as well as soils in southern India during his two brief visits to this country. Mehrotra isolated over fifty species of Mucorales from soils and dung, studying their physiology.

Among Ascomycetous fungi that have been collected and described, mention may be made of *Achaetomium*, *Cerodothis*, *Kokkalera*, *Muelleromyces*, *Thindia*, and *Tripterosporella*. Thind and his group studied some fungi of the Mussoorie Hills and contiguous regions. These floristic studies helped a better understanding of the mycoflora of the region. Thirumalachar made a critical review of smut fungi. Some new genera of rust fungi were established. The Deuteromycetes received adequate attention in India. Subramanian propounded a tentative classification of the Hyphomycetes based primarily on conidium ontogeny. Of particular interest in taxonomy and plant pathology is the correlation between avirulence or virulence noticed in strains of *Fusarium oxysporum* f. *vasinfectum* and *Pyricularia oryzae* and serological patterns. This technique is of potential use in the discrimination of races of pathogenic fungi.

At least twenty races of black rust, sixteen of brown, and ten of yellow have been reported from India. While the bulk inoculum of black rust comes from South India, brown rust spreads from the South (Nilgiri and Palni Hills) as well as the North (Himalayas). Alternate hosts do not play any significant role in the perpetuation of wheat rusts and the intense summer heat of the plains destroys all the rust inoculum of the preceding season.

In recent years certain fungal diseases and their remedies have come in the limelight. Some of these diseases are leaf blight of wheat, red rot of sugar-cane, mango malformation, blast disease of rice, and charcoal rot of potato tubers. Rapid progress has been made on the virus diseases affecting pulse, legumes, cereal crops, and plantation crops. Many of these are seed-borne and aphid-transmitted. Mosaic streak of wheat has been found communicable to large cardamom, ginger, and orchids, although wheat varieties NP 803, NP 809, and E 4647 are known to be resistant. Rice is affected by tungro and yellow dwarf viruses. Maize mosaic virus is transmissible to millets, ragi, and several grasses. Two new virus diseases called 'foorkey' and 'chirki' have been reported from large cardamom. In citrus two new viruses—greening and exocortis—occur singly or in combination. Several diseases of potato have been identified, viz. aucuba mosaic, alfalfa mosaic, leaf roll, A, S, X, and Y.

Several viruses have been purified, their morphology described, and their antisera prepared. Plant viruses can be inhibited by growth products of fungi and bacteria, cinchona alkaloids, plant extracts, growth regulators, and gamma and ultraviolet radiations.

In 1959 bacterial blight of rice was reported from Bombay and became a menace to the successful cultivation of the crop within a short period. Another

bacterial disease of rice, leaf streak, is seed-borne. Bacterial diseases of bajra, jowar, pearl millet, sugar-cane, sorghum, and other crops have been studied. Other bacterial diseases noted are black vein of cabbage; black rot of broccoli, Chinese mustard, knolkhol, radish, and turnip; leaf blight and leaf spot of sesamum; citrus canker; blight of cotton; stalk rot of maize; etc. Phanerogamic and physiological diseases have not received due attention in India.

Since India is very rich in fungal, bacterial, and viral flora, there is great scope for physiological, cytological, and genetical studies on many of these organisms. With the introduction of high-yielding cultivars under intensive irrigation and use of fertilizers, some unimportant diseases have become very serious. Moreover, the detection of diseases by remote sensing has been standardized. We have entered a phase where the focus is on epidemiology and forecasting of plant diseases.

Microbiology: Following the discovery of penicillin, researches on antibiotic production in India were undertaken in a few laboratories in the early forties. The principal contributions originated from Thirumalachar's group at the Hindusthan Antibiotics Limited, Pune. From the species of *Streptomyces* of Indian soils newer antifungal antibiotics—aureofungin, dermostatin, and hamycin—have been made. Whereas the first product is recommended for the control of plant pathogens, the last two are important in fighting the nuisance of dermatophytes. While serving at the Indian Institute of Experimental Medicine, Calcutta, Roy prepared from a strain of *Aspergillus niger*, jawaharene, which was regarded as effective against certain forms of cancer. Nandi and his associates at Bose Institute, Calcutta, isolated an actinomycin-like pigment from *Streptomyces indicus*. Singh and others of IARI reported the development of an antibiotic bulfiformin from a strain of *Bacillus subtilis*. This was effective in seed bacterization in soil. An antibiotic of clinical importance, pentene G8, was obtained by Batra and Bajaj at the Antibiotic Factory of Indian Drugs and Pharmaceuticals Ltd., Rishikesh, U. P.

In the field of industrial microbiology attempts have been made to utilize micro-organisms in the fermentation process to generate amino-acids, organic acids, enzymes, vitamins, etc. At Bose Institute a mutant strain of *Aspergillus niger* has been developed for improved production of citric acid and another strain for the production of gluconic acid. At Haryana Agricultural University (Hissar), the activities include the production of citric and lactic acids as well as a variety of wines from locally-raised grapes. Not only cane molasses but also bean sprouts and hydrolyzed oil cakes have been used for lactic acid production. At the University of Burdwan investigations have been made on the microbial formation of two useful amino-acids, namely, glutamic acid and valine. At the Central Food Technological Research Institute (CFTRI), Mysore, a process for the microbial production of pectolytic enzymes by *Aspergillus aureus* and

Penicillium expansum have been standardized. At Punjab Agricultural University (Ludhiana) it has been demonstrated that fungal proteins can be produced with rice and sugar-cane bagasse as sources of nutrition of the micro-organism.

In the early sixties aerobiology came into existence in India. The incidence of airborne pollen-grains and microbial cells and their implications in spreading plant diseases and allergy in human beings have been studied. The microflora of city air at Calcutta has been surveyed with reference to seasonal variations and geographical locations. The spore contents of the atmosphere have been analysed in relation to human disease. Studies on the occurrence of allergenic fungi and their seasonal appearence have been correlated with the so-called flu epidemic in early November or late February every year when the air temperature reaches a limiting point (max. 30°C. and min. 20°C.). The allergic substance from spores of *Alternaria*, *Aspergillus*, *Cladosporium*, and *Curvularia* has been isolated. Clinical tests on humans indicated *Cladosporium* to be a strong allergen which causes naso-bronchial troubles.

In recent years biological nitrogen fixation constituted an important topic of research in soil microbiology. There are centres of research active in probing Rhizobium-legume symbiosis and legume-seed inoculation with suitable root-nodule bacteria. Studies have been undertaken on rhizosphere microflora of non-legume and legume crops with Mysore soils. Factors influencing rhizosphere microflora of crop plants and their significance in plant-disease control have been stressed. The microbial decomposition process in soil has been considered an important phenomenon in the estimation of soil fertility index. A co-ordinated research project was sponsored by ICAR in various geographical areas of the country with a view to studying the rate of microbial decomposition of soil organic matter under varied climatic conditions, release of mineral nutrients in soil during decomposition, and changes in the physical structure of the soil.

Lichens: The Lucknow school, initiated by Awasthi, played an active role in the advancement of knowledge on Indian lichens. A catalogue of lichens of the Indian subcontinent has been issued. It incorporates the bibliographical and taxonomical information of over 1,300 taxa belonging to 158 genera and fifty families. An account of the macro-lichen flora of Darjeeling district includes several new taxa as does an account of the lichens from Kashmir. The lichen flora of Nilgiri and Palni Hills has been prepared. A new species of *Alectoria* from the Himalayas has been described, clarifying the ambiguity in two other taxa of the genus.

Studies on Indian lichens were also undertaken at the Maharashtra Association for the Cultivation of Science, Pune; National Botanical Research Institute, Lucknow; and Botanical Survey of India, Calcutta. These lichenological investigations dealt with new reports from several regions of the country. Ecological work on the lichens in the neighbourhood of Mirzapur and Varanasi was done

at Banaras Hindu University. There is need for an extensive and intensive survey of the vast lichen flora of the country followed by physiological and biochemical studies.

Bryophytes: Not many persons in India have evinced keen interest in bryophytes, and our present knowledge of this group is due to Kashyap, Brühl, Gangulee, Udar, and Mehra. Kashyap's celebrated work entitled *Liverworts of the Western Himalayas and the Punjab Plain* published in two volumes in 1929 and 1932 constitutes the backbone of the bryological literature of the country. Though old and incomplete, Brühl's *Census of Indian Mosses* is noteworthy. Later, Gangulee published several accounts of the mosses of eastern India.

Udar discovered new species of *Buxbaumia*, *Calobryum*, and *Haplomitrium*, and presented new reports of many liverworts from India. He emphasized the importance of spore morphology in relation to the taxonomy and evolution of hepatics. According to Mehra, the most primitive type of spore is developmentally tetrahedral trilete without any striking ornamentation. From such a type further modifications arose in two different directions—bryophytes and pteridophytes on the one hand and gymnosperms on the other. Perinous spores are considered to be more highly evolved than the non-perinous ones. Significant experimental studies have been conducted on bryophytes. These studies have hinged on the phenomenon of regeneration and modification of their life-cycle.

Pteridophytes: The pteridophytes form an important component of the vegetation in the eastern and north-western Himalayas and the Western and Eastern Ghats in peninsular India. These consist of a single species of *Psilotum*, thirty-two of *Lycopodium*, forty of *Selaginella*, five of *Isoetes*, four of *Equisetum*, and over 750 of ferns spread over 100 genera. A group of classical plants, these have been studied repeatedly as new viewpoints and techniques are sought in botany. In such pursuits the emphasis is not only on morphology, anatomy, life-cycle, geographical distribution, and taxonomy, but also on their correlation with one another—morphogenesis, embryogenesis, ecogeography, and cytotaxonomy.

Beddome prepared *Ferns of Southern India* (1863) and *Handbook to the Ferns of British India* (1863), while Clarke produced *Ferns of Northern India* (1883) and Hope *Ferns of North-Western India* (1899-1902). Panigrahi (1960) listed 150 species of ferns collected from parts of Orissa, Bihar, Assam, and NEFA (now Arunachal Pradesh) with correct nomenclature followed by basionyms and important synonyms. Gupta wrote a monograph on *Marsilea* (1962) and Surange presented an excellent treatise on Indian fossil pteridophytes (1966). Choudhary prepared a worthwhile compendium on the researches dealing with living pteridophytes in India, Burma, and Ceylon (1971). The Universities of Punjab and Kerala are the two most important centres for work on the cytotaxonomy of pteridophytes. Similar work was undertaken at Kalyani and

some other universities. At the University of Poona Mahabale conducted studies on the developmental, morphological, and reproductive aspects of ferns.

The tenets of modern taxonomy require us to consider the morphology of the sporophyte and gametophyte.. Spore morphology is an aid to fern taxonomy. On the basis of spore characters it is easy to recognize various species of *Polypodium*. The shape of spores tends to change from a globose to a bilateral type, being conspicuous in the Aspleniaceae and Polypodiaceae. This suggests that perispore formation can be relied upon for classificatory purpose and phylogeny of ferns within certain limits.

The gametophytes of primitive ferns, the Eusporangiatae, *Lycopodium*, and *Psilotum* are subterranean tubers harbouring profuse mycorrhiza. Whether the tuberization is of adaptive significance or is genic in them is a moot question in the absence of adequate evidence.

PHANEROGAMIC BOTANY

Broad trends in the work on higher plant groups and also present-day thinking on them will be indicated in this section under different subheads as below:

Gymnosperms: In India research on living gymnosperms began only after the return of Sampathkumaran from the University of Chicago. *Cycas* and *Gnetum* caught his attention readily since he was stationed in South India. He frequently delivered talks at the meetings of the Indian Science Congress and showed photomicrographs of *Cycas circinalis* and *Gnetum ula*, but his work was published only in the form of brief notes. From the Forest Research Institute at Dehra Dun Troup published *Silviculture of Indian Trees* (1921) in three volumes, which covered both the gymnosperms and angiosperms. M. B. Raizada and K. C. Sahni brought out in 1958 a treatise on living gymnosperms, covering the genera and species of the Cycadales, Ginkgoales, and Coniferales with detailed morphological description, workable keys and their uses, and diseases and control measures. At the University of Delhi P. Maheshwari gathered round him a team of students whose studies included *Biota, Cedrus, Cephalotaxus, Cryptomeria, Cycas, Pinus*, and *Taxodium*. The cytogenetics of living conifers received considerable attention from Mehra and Khoshoo at the University of Punjab. At the Presidency College, Madras, Swamy, a student of Sampathkumaran, investigated the life-cycle of an Indian species of *Cycas*. Mehra stated that the gymnosperm pollen-grains follow a pattern somewhat different from those of bryophytes and pteridophytes in achieving the primary aims of floatation in the air to reach the micropyle of ovules and then of floatation in the mucilage in the micropylar tube and pollen chamber to bring the germinal area as near as possible to the archegonia to ensure fertilization.

A perusal of the cytology of *Welwitschia mirabilis* by Khoshoo has led to the

suggestion that the genus is highly specialized in its karyotype, which does not indicate any relationship with *Ephedra* and *Gnetum*. This lends credence to the view that the three genera should be accommodated in separate orders—Ephedrales, Gnetales, and Welwitschiales. Konar for the first time made a qualitative survey of the free amino-acids and sugars in the female gametophyte and embryo of *Pinus roxburghii* and a quantitative survey of nitrogenous substances and fats. The main objective in culturing vegetative parts of gymnosperms is to establish continuously growing tissue cultures and to explore the possibility of inducing differentiation of plantlets in such cultures.

Anatomy and Morphology: In his presidential address to the Botany Section of the Indian Science Congress (1922), Dudgeon remarked: 'Since the overwhelming majority of Indian vascular plants are angiosperms, they present a large field of research. Almost no morphological or anatomical work has been done on them.' Happily, the position has changed and we have a band of workers on plant morphology and anatomy. The anatomy of Indian desert plants received attention from Sabnis and that of halophytes and climbers from D'Almeida and Mullan. Joshi gave a critical appraisal of the different views on the morphology of gynoecium. Majumdar and his collaborators made a careful study of the morphology of stipules, ochrea, and bud scales in dicotyledons. The main centres of research in plant anatomy have been strengthened in Vallabhvidyanagar, Bombay, Pilani, Meerut, Dehra Dun, Allahabad, Aligarh, Hyderabad, Madras, and Calcutta. There has been considerable progress in developmental anatomy (of axillary bud, leaf, shoot apex, tendrils, seed, and seedling), general anatomy, floral anatomy, nodal anatomy, systematic anatomy, and wood anatomy of angiosperms.

Embryology: Dudgeon and Sampathkumaran initiated the study of embryology in this country, establishing centres of research at Allahabad and Bangalore respectively. On account of their influence and that of their pupils, India has acquired an international status in embryology. The Botany Department of Delhi University, nurtured by P. Maheshwari, is one of the most active centres, drawing botanists from abroad as well as from this country.

Angiosperm embryology has developed along three distinct lines: (a) classical or descriptive embryology in which the development and organization of gametophytes, endosperm, and embryo have been taken up; (b) comparative or phylogenetic embryology in which the importance of embryological data for determining interrelationships and taxonomic positions stands accepted; and (c) experimental embryology in which initiation and modification of the course of developmental processes have been attempted to understand the genetical and physiological nature in order to bring them under control.

The comparatively new field of experimental embryology has opened up fresh vistas in botanical research. Materials like floral primordium, anther,

pollen-grain, ovary, pericarp, placenta, ovule, nucellus, endosperm, and embryo have been grown on a variety of media and under different physical conditions. Differentiation of flower buds directly from the callus in floral bud cultures has been noticed in *Browallia demissa*, *Phlox drummondii*, *Ranunculus sceleratus*, and in inflorescence-segment cultures of *Majus pumilus*. Differentiation of haploid plants from the anthers of rice, *Datura innoxia*, *D. metal*, and *D. stramonium* has been reported. Attempts have been made with considerable success to culture the pollinated ovaries of *Aerva javanica*, *Allium cepa*, etc. Though embryo development in *in vitro* produced fruits is usually similar to that in nature and viable seeds are obtained, the *in vitro* produced seeds are generally smaller than the natural ones. Test-tube fertilization of ovules has been successfully attained in *Antirrhinum majus*, *Argemone mexicana*, etc. In *Petunia axillaris* placental pollination has been tried and viable seeds secured. It has been possible to establish continuously growing cultures from endosperm of *Croton bonplandianum*, *Exocarpus cupressiforme*, etc. In the field of plant embryology India has made important contributions. However, there are shortcomings in our present knowledge. There is paucity of embryological data on several taxa.

Palynology: In India the study of living pollen-grains and spores in relation to taxonomy, aerobiology, radiation botany, and other aspects is relatively new. With respect to palynotaxonomy, the largest and highest group of plants—angiosperms—has received considerable attention from Indian researchers. Contemporary schools have thrived at Calcutta, Hyderabad, Lucknow, Pondicherry, and Pune. Thanikaimoni compiled in 1972 a bibliographical index on the morphology of angiospermous pollen-grains embracing Indian and extra-Indian territories. Recent findings on the use of pollen-grains in cultivating crop plants have increased the potentiality of agropalynology which involves novel approaches to the methodology of plant breeding, selection of desired pollen materials, their storage, and their controlled use in hybridization programmes of economically important species.

In the sphere of melittopalynology, qualitative and quantitative pollen analysis of Indian honey has been evaluated at the Maharashtra Association for the Cultivation of Science as well as the Central Bee Research and Training Institute, Pune. A catalogue has been prepared, listing major honey- and pollen-yielding plants. Techniques are available to detect the pollen of poisonous plants and isolate it from local honey samples.

Of late, acropalynological research has made substantial progress in India. The Vallabhbhai Patel Chest Institute, Delhi, has played a very active role in organizing this branch with regard to respiratory allergy and other diseases caused by airborne spores and pollen-grains.

PALAEOBOTANY

The study of palaeobotany in India began in 1828 when Brongniart described some Indian fossil plants in his book *Histoire des Vegetaux Fossiles*. In 1838 Royle drew the figures of a few plant fossils in his *Illustrations of the Botany and other Branches of Natural History of the Himalayan Mountains*. Arber reexamined Royle's plants and described the collections of Indian Lower Gondwana plants housed at the British Museum, London. As an officer of the Geological Survey of India, Feistmantel produced the first exhaustive work on the plants of the Lower and Upper Gondwana beds. But research in the twentieth century in palaeobotany started in India only after the return of Birbal Sahni from Cambridge University. At the University of Lucknow important advances were made on the subject under his supervision from 1932 to 1948. This finally led to the establishment of the Birbal Sahni Institute of Palaeobotany at Lucknow. Progress in both pure and applied palaeobotany is largely due to the creation of the Oil and Natural Gas Commission and studies by the Geological Survey. Palaeobotanical studies are conducted at the universities in Pune, Kolhapur, Nagpur, Allahabad, Calcutta, and Burdwan.

Not only anatomical and morphological studies of plant fossils are receiving attention, but palaeobotanical work has been centred round the investigation of acritarchal and algal remains from the Pre-Cambrian and Lower Palaeozoic rocks. Palynological studies of Indian coal seams and their bearing on the stratigraphic position of coal-bearing horizons have been carried out. A palynological biostratigraphic zonation of the Cretaceous-Cenozoic sequence of the Bengal basin and Assam has been suggested. From crude petroleum deposits and bore-hole cores of the Tipam sandstone stage of the Digboi oil field, it has been concluded that the crude must have migrated into the Tipam formation from some other rock. Pollen analysis of quaternary deposits of the Nilgiris, western Himalaya, Rajasthan, and West Bengal has been performed to reconstruct the vegetational history and the related palaeoenvironment. Studies in vegetational history have provided useful information of the environmental background of early man in the country as well as the origin and progressive development of farming activity. Ancient plant economy of neolithic to late historical cultures and the history of a wide variety of food grains has also been reconstructed.

It would be rewarding to do palaeobotanical work in such fossil-rich areas as Kashmir, Gujarat, South India, and Bihar. Our knowledge of the flora of Pre-Cambrian and Lower Palaeozoic rocks of India is still far from complete. There exists a vast scope to make more fruitful contributions towards the knowledge of the world's microfossil, although significant findings have emerged recently from microfossils in Archaeans, Bhimas, Cuddapah, Dharwar, and Vindhyans. A modest beginning has been made in the domain of quaternary

deposits and the Quaternary Research Society of India has been formed to know more of our immediate past.

CYTOLOGY

Cytological research in India began in the twenties of this century. A vast amount of work on the cytology of lower and higher groups of plants has since accumulated. Improvements in methodology, the availability of materials, and the application of methodology to current problems have influenced progress in cytology in three major phases. The first is limited to sheer records of chromosome numbers, principally from meiosis. The second phase is concerned with the utilization of research on chromosome structure and behaviour in examining the mutagenicity of various physical and chemical agents and in solving problems of taxonomic importance. The third phase deals with an analysis of the dynamicity of chromosome structure and its chemistry in relation to different stages of growth and differentiation.

The first phase in cytological work is almost over, except for stray reports from the Botanical Survey of India and a few laboratories being published in journals. The study of chromosomes in relation to structure, taxonomy, phylogeny, and evolution has been conducted. The main contributors have been the university departments at Calcutta, Patna, Delhi, Chandigarh, Dharwar, Mysore, Trivandrum, and Waltair. The Calcutta centre under the leadership of A. K. Sharma, a recipient of the 1967 Bhatnagar award for outstanding contributions in botany, is the largest school of chromosome research in India. With thorough cytological exploration of most taxa, the approach has changed and attention has been directed towards the study of species complex to pinpoint the factors influencing their evolution and the correlation of cytotypes with ecological preferences.

Any chromosomal change, not causing sterility of the gametes, may result in new forms. A. K. Sharma has made the interesting observation that in some vegetatively propagated members of the Araceae, Amaryllidaceae, and Dioscoreaceae the same root tip shows the presence of cells with chromosomes of varying size and number. He has put forward the concept that changes in karyotypes of somatic tissue play a distinct role in evolution. By resorting to this method many species have been evolved with specialization in divergent directions. With advancements in chromosome technology, cytology has evolved from the level of an adjunct to taxonomy and genetics to an interdisciplinary science and is progressing towards the comprehension of the cell as an integrated dynamic unit.

GENETICS AND PLANT BREEDING

Scientific plant breeding started in India soon after the rediscovery of Mendel's Laws. The Botany Division of the Indian Agricultural Research

Institute (IARI) at New Delhi is a pioneer centre for applied and fundamental research on cytogenetics. During the first phase of the work, ending in the fifties, breeders were needed to produce varieties for conditions of average soil fertility. In the second phase which began nearly thirty years ago, the purpose was to develop high-yielding cultivars that would respond to a high level of management by way of the use of chemical fertilizers. Mention may be made of improved wheat varieties which are very rich in quality and compare favourably with some of the best wheats of the world.

Another impressive contribution in the early years relates to the breeding of disease-resistant varieties of sugar-cane through interspecific hybridization. These sugar-cane varieties, which led to the development of a prodigious sugar industry in India, have been widely distributed in many parts of the world. Several fertilizer-responsive, high-yielding varieties of rice have been bred at different research institutes and extensive trials have been made with them throughout the country. These have led to the breeding of new plant types which are suitable for various agro-climatic conditions of the country. A number of new arhar varieties developed during recent years exhibit reduced vegetative growth and an erect habit combined with a high harvest index. Some of them permit a population of 72,000 plants per hectare as against 35,000 of the older types and have a maturity period of about five months, which is about half of the traditional types. With the aid of these improved varieties, it is possible to cultivate arhar in rotation with wheat. In the case of moong, short-duration varieties (Pusa Baisakhi) which are ready for harvest within a period of seventy days can be raised as an additional crop in the summer between the main *rabi* and *kharif* seasons. Some of the new cotton varieties respond to an optimum of 40,000 plants per acre and yield twenty quintals of seed cotton over a one-year period. Several rust-resistant strains of linseed developed by crossing the indigenous stocks with exotic genetic types have become popular in Rajasthan, Uttar Pradesh, Madhya Pradesh, and Bihar. Not only has the maturity duration of the brown sarson crop been cut down to 110 days, but also a record yield of twenty-five quintals per acre has been obtained. Pusa Giant berseem, an artificially produced tetraploid strain, is comparatively resistant to low temperatures and gives 20-30% more fodder than the existing diploid types. Another fodder variety (Pusa Giant Napier), produced by crossing *Pennisetum purpureum* and *P. typhoides*, yields over 110 tonnes of fodder per acre.

PHYSIOLOGY

The name of Jagadish Chandra Bose is invariably associated with the study of plant physiology in this country. He devised instruments for measuring growth, leaf movements, contractions in stem diameters, and responses to

various stimuli. He showed that the touch stimulus was conducted along the petiole as an electric action potential which was very sensitive to the direction of the current, to cooling, or to treatment with alcohol and other chemical agents. He claimed the existence of a certain type of peristaltic activity in the stems for the ascent of sap and demonstrated that the convex side of a curved stem was electropositive.

The work started by Bose was continued for some time by his illustrious student, Boshi Sen. In his earlier years Sen was concerned with changes in permeability as related to plant movements. In later years he delved in vernalization and built up the Vivekananda Laboratory at Almora where he worked steadily till his death in 1971.

A firm foundation for the study of plant physiology was laid in India when Dastur, Ekambaram, Inamdar, and Parija returned from England after higher studies and established their own schools of research at Bombay, Madras, Varanasi, and Cuttack respectively. Dastur and his group worked on factors influencing photosynthesis, mechanism of flowering, physiology of mangrove plants, and 'Tirak' disease of cotton. Ekambaram's contributions were on the problems of leaf-fall and the annual variation of respiration in tropical plants. Parija investigated the mode of perennation and control of water hyacinth, the stimulation of respiration of detached leaves in light, as well as the acceleration and induction of drought resistance by pre-sowing high-temperature treatment.

A number of schools of plant physiology have grown in India. Trained by Dastur, Chinoy started the Ahmedabad school which has dealt with the action of ascorbic acid in relation to photoperiod and temperature on germination, and growth and reproductive phases of wheat and other crop plants. Nanda, earlier associated with Chinoy at Delhi, studied at Chandigarh the photoperiodic response of *Impatiens balsamina* and its relationship to growth of stem, structural changes in the shoot apex, as well as their correlation with initiation of flower buds and leaves, aging of plants, and chemical control of flowering.

Studies aimed at understanding floral differentiation and morphogenesis were taken up in the sixties at the University of Delhi. S. C. Maheshwari and his co-workers reported a condition for improved bioassay of auxin, using two oat varieties available in India. They indicated the presence in water-melon juice and cucumber of new substances conducive to plant growth. They also confirmed the role of chelating agents and iron in the modification of growth and flowering of short-day plants *Lemna paucicostata* and *Wolffia microscopica*.

At IARI contributions on the physiology of drought resistance and net assimilation of wheat were made by Asana and his associates after a perusal of the importance of environmental factors including water supply for the filling

up of grains of different varieties. Sarin's group studied the physiology of salt tolerance, photoperiodic behaviour of crop plants, and hormonal action in the inhibition of flowering. Ved Prakash recorded the effect of growth substances on morphological and biochemical changes in cotton and wheat seedlings. Studies on the lodging resistance of crop plants on a comparative basis and the effects of various photoperiodic regimes and gibberellic acid on growth and yield of cotton and wheat from different agro-ecological regions of India have been made by Sirohi and his pupils. Gautam noted a suitable basis for expressing plant pigments and their presence during ontogeny.

The Allahabad school, under the guidance of Ranjan, a student of Inamdar, worked on respiration and metabolism. Laloraya, a student of Ranjan, investigated the precise role of plant pigments on the action of gibberellic acid. The influence of hormones and nucleic acids on vegetative growth and flowering has been reported by workers of Allahabad University.

Agarwal of the Lucknow school studied the effects of trace elements like molybdenum, cobalt, nickel, chromium, and iron on plant growth. At Gorakhpur Mathur investigated the effects of photoperiod, growth substances, and purine and pyrimidine bases and their analogues on the metabolic drifts, flowering, and fruiting of cotton and dahlia. At Kanpur Mehrotra studied the effect of soil moisture and boron nutrition on germination, growth, and yield of groundnut. At Agra Kaul and Singh were concerned with the effect of certain chemicals on vegetative growth, flowering pollen viability, and induction of male sterility in onion and wheat. At Banaras B. N. Singh, another pupil of Inamdar, dealt with photosynthesis, respiration, and water relations. Two of Singh's students include Lal and Chaudhri. Lal's studies covered the drought resistance and mineral nutrition of several crop plants. Chaudhri showed the effects of synthetic growth regulators on the growth and development of onion, radish, and tomato. At Chaubatia Tewari observed the physiological changes in fruits of Buckingham apples.

After Parija the Cuttack school developed first under Samantarai and later under G. Misra. They followed the influence of growth hormones and photoperiod on the flowering and yield of rice, wheat, and other plants. At Bhuvaneswar D. Misra registered the changes in the amino-acid contents of rice shoot and the effects of indole-acetic acid, benzimidazole, and B-nine on the nodulation of cowpea.

At Tirupati Rao and Ramdas made physiological studies, the former in salinity and viability and the latter in metabolism and plant chemistry. At Coimbatore Bhat studied the cause of low germination of Indo-Gangetic linseed variety, catalase activity in roots during pathogenesis, and changes in carbohydrate content during bolling of cotton. At Rajamundry N. L. Pal and others noticed the effects of growth substances and radiation on aerial

rooting, seed germination, and the quality of tobacco. At Trivandrum Sinha and other workers explored the possibility of controlling increasing cyanoglucoside contents in cassava tubers by the use of nitrogen as a foliar spray.

At the University of Jodhpur U. N. Chatterji proved the effects of inhibitors on seed germination and root growth of various plants. D. N. Sen, a student of Chatterji, demonstrated the presence of different pigments in *Euphorbia caducifolia* and stressed the specific role of potassium ions in light-induced stomatal opening of *Calotropis procera*. Lahiri of the Central Arid Zone Research Institute, Jodhpur, studied water economy, micro-nutrient deficiency, germination, and exogenous synthetic growth substances.

The Calcutta school, with Sircar as a guide, investigated many aspects of the rice plant from the basic to the agronomic and contributed much to our knowledge of photoperiodism, vernalization, mineral nutrition, photosynthetic efficiency, germination, viability, and naturally occurring hormones. At Bose Institute a group led by Biswas studied chloroplastic protein synthesis, claiming hormone-stimulated enzyme synthesis by causing the formation of a particular messenger RNA. At the University of Kalyani S. P. Sen and his associates indicated that plant hormones stimulated the synthesis of nuclear RNA and protein, and that the site of hormone action was the nucleus. They initiated tracer studies on biochemical aspects of flowering and recorded the translocation of photosynthetes and amino-acids from leaves to apices in relation to photoperiodic treatment. They also reported the photosynthetic production of oxalic acid in *Oxalis corniculata*. At the University of Burdwan S. K. Chatterjee and his students investigated the mechanism of abscission and senescence of various plant organs.

Two of Sircar's students—Mukherjee and Datta—did researches at the University of Calcutta. Mukherjee's group studied the effect of hadacidin and other growth regulators on changes of α-amylase production in germinating rice seeds as well as the effects of metal toxicity and various chemicals on seedling vigour, enzyme activity, and nucleic acid metabolism. Datta, the author of this article, worked on the potassium nutrition of rice plants, light effects on phytotoxicity with respect to herbicides, and post-harvest physiology of fruits. Germination-regulating mechanisms of seeds of angiosperms and the physiological ecology of wild plants were studied by Datta and his associates.

ECOLOGY

For making better use of the natural resources of India ecological and phytogeographical studies were started early in the twentieth century. Monumental work was done by members of the Agriculture and Forest Departments of the Government of India. These enthusiastic workers included foreigners, chiefly British officers of the Indian Civil Service and Medical

Service, and Indian scientists. Hooker rendered yeoman's service to the cause of Indian botany through his exhaustive *Flora of British India* (1875). A very complete list of the flora of western India was compiled by Cooke. Hole made a study of the sal tree and forest grasses. This early period of botanical research was important, as knowledge of the flora is a prerequisite of any ecological study.

Agharkar of the University of Calcutta was serving in Berlin as a research student prior to World War I. His paper entitled 'The Means of Dispersal and the Present-day Distribution of the Xerophytes and the Sub-xerophytes of Northwest India' appeared in 1920. He may be considered as the pioneer worker on Indian ecology. About the same time two Jesuit Fathers of St. Xavier's College—Blatter and Hallberg—were studying the vegetation of the Thar desert. Saxton and Sedgwick turned their attention to a similar study of the arid regions of Gujarat. But these two studies were essentially floristic. Dudgeon's study of the Gangetic plains and that of Kenoyer on plant succession were the first attempts at genuine ecological work. To the same period belong the accounts of plant formations in Bihar and Orissa and of the riverine tracts of Burma by Stamp and Lord.

Slowly the early work in India was diverted to another branch of botany, i.e. plant geography. The pioneer phytogeographical work of Burkill on Arborland was followed by those of Dudgeon and Kenoyer on the vegetation of Tehri-Gharwal, Cowan on the forests of Kalimpong, Kashyap on the vegetation of the Himalayas and western Tibet, and Sabnis on the flora of the Punjab and the adjoining hilly regions.

Mullan worked on ecological plant anatomy with particular reference to the mangroves so abundantly found in Bombay swamps. Burns studied the Deccan grasslands primarily from a successional viewpoint. Gorrie dealt with the ecology of the Sutlej deodar (*Cedrus deodara*). Champion's masterpiece, *A Survey of the Forest Types of India and Burma*, was first published in 1936. It was subsequently revised by Champion and Seth in 1973. Ecology began to be introduced as a special subject in Indian universities from the late thirties and its study was facilitated by the return from Europe of two Indian students trained in ecology, F. R. Bharucha and R. Misra. The latter, after carrying out extensive researches on the ecology of English lakes under the inspiring guidance of Pearsall, initiated his studies on the autecology of Indian plants. Later he combined these studies with synecological studies on forests and grasslands and thus established his School of Plant Ecology, the largest in India, at Banaras Hindu University. These studies continued till 1965 when, influenced by Odum, he switched over to work on productivity and ecosystems.

Extensive research on almost all aspects of ecology was done by Misra

and his numerous students throughout the country. A complete bibliography on the subject was published by the Indian Botanical Society in 1955. Furthermore, Misra and Puri (1957) reviewed the progress in ecological research in India. They also described the community ecology of Madhya Pradesh and eastern Uttar Pradesh. Puri (1982) reviewed the literature and problems of forest ecology. Mention may be made of the study of aquatic vegetation, algal ecology, and ecology of sand-dunes and miscellaneous habitats.

While Misra specialized in ecology, Bharucha specialized in both ecology and phytosociology, having worked under Godwin at Cambridge and subsequently under Braun-Blanquet at Montpellier. Forming his own school at Bombay in 1935, Bharucha initiated his studies with work on the ecology of mangroves and gradually took up the case of Indian grasslands. These aspects ushered in investigations on the biological spectra of the flora of a number of regions. After this Bharucha and his associates probed the arid zones and the Thar desert on which the former was commissioned by UNESCO to write a report. He also created a new system of delineating the vegetational zones on the basis of vegetation as the parameter and not on the basis of climate.

Studies by Misra and his colleagues concentrated on ecosystem productivity, a new concept in Indian ecology. Reference may also be made to Pandeya, who worked along the lines of his teacher, Misra, and also followed his own line of interest. He began with the autecology of various species and then made large-scale studies on grasses, weeds, and trees. According to him, ecotypic differentiation equips a species to tide over biotic, climatic, or edaphic barriers.

The work of D. N. Sen at the University of Jodhpur on ecophysiological studies was a welcome innovation, as physiology plays an important part in the growth of plants and the ecological studies of different kinds of vegetation. Similarly studies on the autecology of aquatic and terrestrial weeds of West Bengal have been made by Datta and his small group at the University of Calcutta.

In scanning through the botanical literature that appeared during the last 100 years in India, we are amazed at the developments in various fields of botany. As we are nearing the end of the present century, we find that Indian botany has already come down to the molecular level and we can expect exciting discoveries in the not-too-distant future. Co-ordinated efforts and interdisciplinary approaches are much required not only to exploit the plant wealth of the country but also to conserve it for posterity. It is necessary to organize long-term conservation of plants in germ-plasm collections or gene sanctuaries and have seed banks or pollen banks. Conservation of meristem and photoplast culture is the domain of specialists in tissue culture. There

is also a need for protecting plant resources in the field by the designation of biosphere reserves all over the country. Electronic data-processing, information-retrieval system, popularly called computer methodology, is another promising realm.

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ZOOLOGY

INTRODUCTION

A serious study of the history of any branch of science in a country needs support of data documented in the past. Historical research into the development of zoology in India during the last 200 years can be done with an analytical approach or by attempting to get a synoptic insight into the pattern of growth. The earliest study of the subject was made by F. H. Gravely[1] in his address to the zoology section of the eighth session of the Indian Science Congress held in Calcutta in 1921. He dealt with the history of zoology in India and Sri Lanka since 1659. In the Silver Jubilee (1938) volume of the Indian Science Congress Association (ISCA) Srinivasa Rao[2] updated the information on the progress of zoology up to 1938. A reference was made to this by G. Mathe at the twenty-fifth session of the Indian Science Congress. It was again under the aegis of ISCA that B. S. Chauhan and C. B. Srivastava of the Zoological Survey of India (ZSI) were assigned the task of compiling an account of the development of zoology in India (1938-62); but it remained unpublished. The progress of zoology and entomology can be further traced in *A Decade (1963-72) of Science in India*[3] published by ISCA. The present author had the opportunity to work further on the subject to contribute information in the volume entitled *Science in India: A Changing Profile*[4] published by the Indian National Science Academy (INSA). The aforementioned accounts provided the most vital sources of information documented at different intervals of time. A distinct feature of the development of zoology in India in the nineteenth century appears to be its growth around some pioneers, in many cases from other disciplines. While contributions from Indian scientists during the first hundred years under review may not appear significant, the course of events in the present century made it doubly reassuring with the expansion of higher education and research, specially during the post-independence period.

[1]Vide *Proceedings of the Asiatic Society of Bengal*, N. S. XVII, pp. cxxxii-cxivi.

[2]*Progress of Sciences in India During the Past Twenty-five Years*, ed. B. Prashad (Indian Science Congress Association, 1938), pp. 352-433.

[3]S. P. Raychaudhuri, 'Progress of Zoology and Entomology' in *A Decade (1963-72) of Science in India* (ISCA, Calcutta, 1973).

[4]S. K. Mukerji and B. V. Subbarayappa, *Science in India: A Changing Profile* (Indian National Science Academy, New Delhi, 1984), pp. 20-21.

The present account, however, has its own limitations. While an attempt has been made to trace the contribution of the early pioneers of the nineteenth century towards the development of zoology, greater emphasis has been laid in the study of the progress during the twentieth century on the broader spectrum of the discipline by way of higher education, research and development, and governmental support.

EARLY PIONEERS AND THEIR WORKS

The major landmarks of zoology in India in the nineteenth century comprise the lasting contributions of outstanding workers in the field. The account presented here deals mainly with personalities who are inseparable from the development of zoology in India. The first to mention is Francis Buchanan, a native of Edinburgh, who came to India as an Assistant Surgeon in the East India Company's service in Bengal in 1794 at the age of thirty-two. Soon after his arrival in Calcutta, Buchanan had to visit the Andaman Islands. On his return, he was posted at the Sundarbans. Both the areas offered him enough collections of island and estuarine fauna, and he started drawing sketches of some fishes of the Sundarbans. Buchanan later adopted a second name, Hamilton Buchanan, and travelled extensively in South India, Nepal, Assam, and other areas. On his retirement, he published in 1822 an account of the fishes found in the river Ganges and its branches and included in it his drawings made up to 1800. Hamilton Buchanan made careful observations on fish and fisheries during his assignment to make a 'statistical survey of Bengal and certain adjacent districts in 1806'. But the results were only published in the twentieth volume of *Statistical Account of Bengal* by Sir William Hunter[5] long after Buchanan's demise in 1820. F. H. Gravely (1921)[6] mentioned that drawings made by Buchanan and his manuscript were held in the custody of the Asiatic Society of Bengal.

A work on the largest faunal group amongst invertebrates, the insects, was first published in 1800 by E. Donovan. The volume, subsequently revised and published by J. C. Westwood in 1842, also included insects of the East and West Indies.[7]

Contributions of military personnel often appear to be remarkable in the field of Indian zoology. Major General Thomas Hardswicke published a series of papers between 1798 and 1834, all based on his excellent collections. The significant publication *Illustrations of Indian Zoology* (1830-32) by Gray

[5] W. Hunter, *Statistical Account of Bengal*, Vol. XX (1877).

[6] F. H. Gravely, Presidential Address, Section of Zoology, Proceedings of the Ninth Indian Science Congress (1921), *Proceedings of the Asiatic Society of Bengal* (N. S.).

[7] E. Donovan, *An Epitome of the Natural History of the Insects of India* (London, 1800-1804).

depicted a large number of vertebrate fauna of the area, selected from the collections of Major General Hardswicke.[8]

N. Annandale[9] (1922) in his presidential address to the Indian Science Congress on 'Ethics of Zoology' mentioned the inaugural discourse by Sir William Jones to the Asiatic Society delivered in Calcutta in 1784, where he omitted zoology from the proposed agenda of the Society. Nine years later, Jones in his tenth address to the Society explained: 'Could the figures, instincts, and qualities of birds, beasts, insects, reptiles, and fishes be ascertained either on the plan of Buffoon or on that of Linnaeus without giving pain to the objects of our examination, few studies would afford us more solid instruction or more exquisite delight.' However, it was Bryan Houghton who introduced the subject of zoology to the Asiatic Society of Bengal and presented a series of valuable specimens to the Society's museum. Hodgson's work made Calcutta the main centre of zoological research in India and his papers over two decades (1824-48), numbering more than one hundred, published in *Researches and Journal of Asiatic Society*, specially dealt with the birds and mammalian fauna of Nepal, Sikkim, and Tibet. They constitute one of the earliest contributions on high altitude zoology.

In 1830 Dr H. Falconer joined as Assistant Surgeon in the East India Company's service and simultaneously started study of the fossil bones in the Asiatic Society's collections. Later, Falconer extensively collected and studied the animal fossil remains of Siwalik Hills in the Sub-Himalayan Range, including fossil species of Camel and Hippopotamus. In 1859 the Asiatic Society published *A Descriptive Catalogue of Fossil Remains of Vertebrata from Siwalik Hills, the Narmada, Perim Island, etc. in the Museum of Asiatic Society of Bengal.* Earlier, in 1837, Falconer was awarded Medal of the Geological Society, when he was under thirty, and subsequently other societies of Europe and America bestowed on him appropriate honours. On his death, a marble bust of his was placed in the Royal Society, London.

Further work on invertebrate zoology following Donovan's (1800) appeared after a gap of nearly thirty years when papers on molluscan shells were published by W. H. Bensen and T. Hunter, and the work was continued by W. T. Blanford, H. F. Blanford, W. Theobald, H. Godwin-Austen, F. Stoliczka, and Geoffrey Nevill. The first volume on Mollusca under the *Fauna of British India* series was authored by W. T. Blanford and H. Godwin-Austen in 1908. Simultaneously appeared during the period the results of study on fresh-water sponges by H. J. Carter in 1847 in *Transactions of the Bombay Medical and*

[8] J. E. Gray, *Illustrations of Indian Zoology* (London, 1830-32).
[9] *Proceedings of the Asiatic Society of Bengal* (N. S.), XVIII (1922).

Physical Society and in *Annals and Magazine of Natural History* on insects of the Himalayas[10] and on invertebrate fauna.[11]

W. T. Blanford was an officer of the Geological Survey of India during 1855-82 and made untiring efforts to start the *Fauna of British India* series which was sanctioned in 1883. The first volume on Mammalia by Blanford[12] himself appeared in 1888. He also contributed two of the four volumes on birds[13] and also started work on the first volume on Mollusca, later completed by Godwin-Austen and published, as mentioned earlier, under their joint authorship. Blanford's excellent collections over the years, his series of papers in the *Journal of the Asiatic Society of Bengal*, and, above all, his efforts to establish the Indian Museum as a Government institution and initiate zoological work on board the ship *Investigator* as a part of marine survey of India made him one of the outstanding figures of Indian zoology in the nineteenth century. One of the other pioneering figures deserving special mention is Ferdinand Stoliczka. Like Blanford, Stoliczka joined the Geological Survey of India in 1862, coming all the way from Vienna. Till his untimely death in 1874 at Ladakh on his way to Central Asia, he made a series of fascinating contributions on the internal anatomy of sea-anemones, arachnology, molluscs, frogs and reptiles, and osteology. Several of the reptilian specimens collected earlier by Stoliczka remained in Vienna, but all his later collections formed an invaluable part of the collections of the Asiatic Society and then of the Indian Museum.

In the *Centenary Review of the Asiatic Society of Bengal* (1784-1883) it is mentioned that it was in 1869 that Stoliczka commenced in this country a systematic study of the anatomy, physiology, and morphology not only of mollusca, but also of other invertebrates.

After twenty years of Hodgson's venture of zoological studies in the Asiatic Society, John McClelland, a member of Bengal Medical Service, was appointed Curator of the Society's museum in 1839. He held this post only for a brief period of two years and was succeeded by Edward Blyth. John McClelland started a journal, one of the earliest journals of natural history in India, entitled *Calcutta Journal of Natural History* in which a series of important contributions were published between 1841 and 1847.

Edward Blyth can be credited mostly for his unstinted efforts to expand the Society's museum collections in zoology till his retirement in 1864. His

[10]F. W. Hope, *Madras Journal of Science*, Vol. XII (1840), pp. 105-29.

[11]F. Stoliczka, *Journal of the Asiatic Society of Bengal*, Vol. XXXVIII (1869).

[12]W. T. Blanford, *Mammalia: Fauna of British India Including Ceylon and Burma* (Taylor and Francis, London, 1888).

[13]W. T. Blanford, *Birds: Fauna of British India Including Ceylon and Burma*, Vols. III and IV (Taylor and Francis, London, 1895-98).

published works include catalogues of birds[14] and mammals[15] in the Asiatic Society's collections. Blyth is aptly mentioned as 'the founder in this country of a school of what may be called field zoologists'. Even Charles Darwin quoted Blyth as an 'excellent authority'.

There were several other notable publications on the vertebrate fauna of India during the same period, that is in the 1830s. Of these Thomas Caverhill Jerdon's work on birds needs special mention. A series of catalogues and manuals of birds and mammals of South India, Maharashtra, Uttar Pradesh, Bihar, and Bengal by W. H. Sykes,[16] Major James Franklin (1831), Lt. S. R. Tickell (1833-65), Col. Godwin-Austen, and Sir Walter Elliot (1839), mostly published in the *Journal of the Asiatic Society of Bengal* and also in the *Madras Journal of Literature and Science*, formed the basis for future work in vertebrate zoology in India. Like many other notable contributors, Jerdon was an officer of the Madras Medical Service and later joined the 4th Light Cavalry. Subsequently, with support from Lord Canning in Calcutta, he started his works on manuals of Indian vertebrates. He worked on Aves for the *Fauna of British India* series which was published in two volumes in 1862-63, followed by his volume on Mammalia in 1867. He continued his manuals on reptiles and fishes. After his retirement from service in 1870 he died of severe illness in England in 1872. Jerdon's book on reptiles was never published and his work on fishes remained incomplete. Subsequently, Guenther's work on 'Reptiles of British India'[17] published in 1864 and Francis Day's work on 'Fishes of India'[18] filled up these gaps. Francis Day was an officer of Madras Medical Service and during his extensive tours in South India and study of seven of the major rivers of the east coast, besides the drainage system of Orissa, Bengal, Burma and Andamans, and other areas, he could collect, study, document, and finally publish the monumental works which remain unsurpassed in the ichthyological branch of zoology in India.

The *Catalogue of Recent Shells in the Museum of Asiatic Soceity of Bengal* by Theobald published in 1869 was followed, even after the transfer of the collections to the trustees of the Indian Museum, by a series of other publications like *Monograph of Asiatic Chiroptera* by Dobson (1876), *Catalogue of Mollusca* by Nevill (1877), and *Catalogue of Mammalia* by Anderson and Sclater (1881-91). During the same period two expeditions were conducted through Burma

[14]E. Blyth, 'Catalogue of Birds in the Museum of Asiatic Society': Supplementary Note to the Catalogue, *Journal of the Asiatic Society of Bengal (JASB)* (N. S.), Vol. XVIII (Calcutta, 1849), p. 800.

[15]E. Blyth, 'Catalogue of Mammalia in the Museum of Asiatic Society of Bengal', *JASB* (Calcutta, 1863).

[16]W. H. Sykes, *JASB* (1832).

[17]A. C. L. G. Guenther, *The Reptiles of British India* (London, 1864).

[18]F. Day, *The Sea Fishes of India and Burma* (Calcutta, 1873); also his *The Fishes of India, Burma, and Ceylon* (London, 1876-78).

and Western China in which J. Anderson, Superintendent of the Indian Museum, participated. The zoological collections of the expeditions provided the material for extensive research, both anatomical and systematic, for Anderson himself as well as other workers in Calcutta. The results were published in two volumes of text and plate from London under the title *Anatomical and Zoological Researches, comprising an account of the zoological results of the two expeditions to western Yunan in 1863 and 1875* and in a monograph on the two Cetacean genera, Platanista and Oriella.

Reference has already been made to the *Fauna of British India* series under the editorship of W. T. Blanford who himself authored the first part of the first volume on mammals in 1888. The whole series published up to 1900 included *Hymenoptera* by C. T. Bingham (1897); *Lepidoptera: Moths* (Vols. I-IV) by G. F. Hampson (1892, 1894, 1895, 1896); *Arachnida* by R. I. Pocock (1900); *Pisces* by F. Day (1889); *Amphibia* by G. A. Boulenger (1890); *Reptilia* by G. A. Boulenger (1890); *Aves* (Vols. I-IV) by E. W. Oates (1889, 1890, 1895, 1898); and *Mammalia* (Parts 1, 2) by Blanford (1888, 1891). The list clearly indicates the state of knowledge of all vertebrate groups and a few invertebrate groups of animals in India by the turn of the last century. The *Fauna of British India* series provided by far the most notable source of information on Indian fauna. The trend of research and its tempo clearly showed a new dimension, but avenues for publication of research findings remained restricted to the *Madras Journal of Literature and Science* (1833-73), *Calcutta Journal of Natural History* (1841-47), *Stray Feathers* (1872-88), *Journal of the Asiatic Society of Bengal* (preceded by *Transactions of the Medical and Physical Society* and *Gleanings in Science*), etc. The Bombay Natural History Society founded in 1883 started a new *Journal of the Bombay Natural History Society* in 1886, and J. A. Murray almost at the same time issued a magazine called *Indian Annals and Magazine of Natural Science* from Victoria Natural History Institute, Bombay.

In the centenary volume published by the Asiatic Society in 1885, a complete list is given of all the papers on zoological subjects from India. This list 'gives a very fair idea of the manner in which the collections that accumulated at the time of Blyth (1841) and his predecessors and immediate successors were utilized for the purpose of research'. The list includes 364 papers under vertebrata and 150 papers under invertebrata, many of which still provide valuable data.

Gravely (1921) mentioned that none, even among the founders of the Calcutta centre of zoological research, with the possible exception of Edward Blyth, was a professional zoologist. Their zoological work, as we have already seen, centred round the Asiatic Society of Bengal, a private society which was supported by their own work and subscription, and by those of their fellow members. Yet it was due to their efforts and those of their successors that

the provision by the Government of the facilities for researches came about. In the *Centenary Volume of Indian Museum* (1814-1914), Asutosh Mookerjee mentioned five sources of zoological collections of the Indian Museum: (i) old collections of the Asiatic Society; (ii) marine collections made by successive Surgeon-Naturalists on board the R.M.S. *Investigator*; (iii) collections made on military and political expeditions; (iv) gifts of private donors; and (v) collections made by members of the museum staff. Of those, the collections of (ii) and (v) can only be said to have had support of the Government.

The Marine Survey of India started its biological studies in 1871 when the Council of the Asiatic Society of Bengal appealed to the Government of India for undertaking investigation in Indian waters, similar to the one done by H.M.S. *Challenger*, appointed by the British Government, in respect of life and matter of great oceans. The appeal of the Asiatic Society was based on the recommendation of a committee composed of F. Stoliczka, W. T. Blanford, J. Anderson, J. Wood-Mason, and T. Oldham, who opined that deep-sea investigation might lead to the discovery of new animal forms. The proposal was supported by the Royal Society of London and by many of the contemporary leading zoologists. But credit for the first deep-sea biological investigations of the Indian Ocean goes to James Wood-Mason of the Indian Museum, who, with limited facility, collected specimens from shallow water up to about 300 fathoms. In 1875 the post of Surgeon-Naturalist of the Marine Survey of India was created and filled up by Dr J. Armstrong, who, without the aid of a ship, had to restrict his work to the shallow water and littoral region. He published in the *Journal of the Asiatic Society of Bengal* a brief but excellent paper on hydroid zoophytes from Indian coasts and seas. Deep-sea dredging at last took its proper, if secondary, place in the economy of Marine Survey of India. With Surgeon-Naturalist G.M.T. Giles on board the R.I.M.S.S. *Investigator*, several areas were surveyed in 1884-85 and 1886-87 and the collections were studied during the recess season. Giles published a series of papers on marine animals of Indian waters in the *Journal of the Asiatic Society of Bengal* (1885-90), which constituted the basis of his future work. In 1888 Giles resigned, and at the end of the year Capt. A. Alcock was appointed in his place. The latter was succeeded by Surgeon-Captain A. R. S. Anderson (1893-99). Several areas of the Bay of Bengal, the sea around Sri Lanka, the Andamans, Palk Straits, Lakshadwip, the mouth of the Ganges and the Indus, etc. were extensively surveyed. With the appointment of artists like A. C. Chowdhury and later, S. C. Mondal, a series of twelve plates per year were prepared and published in the 1890s as *Illustrations of the Zoology of the Royal Indian Marine Surveying Steamer Investigator*.

However, the first of the monographs based on collections made by the *Investigator* was published by Alcock in 1898 on Madreporaria followed by three more volumes, *The Deep Sea Ophiuroidea* by R. Koehler, *The Deep Sea Fishes* by Alcock, and *The Deep Sea Brachyua* by Alcock—all being published in 1899.

The foregoing brief account shows certain definite trends of research and investigation. As Gravely noted in 1921: 'In Europe, with its comparatively limited and well-explored fauna, morphology commonly offers much greater scope for investigation than does taxonomy. In India, with its much richer and largely unexplored fauna, this is not so, and thus it happens that all the greater Indian Zoologists have hitherto been taxonomists. But their taxonomic work has been based on careful investigations into anatomy and field biology, thereby establishing for us a fine tradition.'

STUDY OF ZOOLOGY IN THE TWENTIETH CENTURY

Institutional Expansion in Early Years: The progress of the study of zoology for the first four decades of the twentieth century has been well documented by H. Srinivasa Rao (1938). He aptly remarked that besides the Royal Asiatic Society of Bengal and the Bombay Natural History Society, no organized institutions made any effort in the past in fostering or stimulating research in zoology. The Indian Museum of Calcutta (estd. 1814), the museum at Madras, the colleges at Lahore, Madras, and Allahabad were the only other places of worthwhile research and training in the discipline till the start of expansion of education and the growth of institutions in the early years of the twentieth century.

The Zoological Survey of India (ZSI) was established in Calcutta in 1916 for systematic exploration and research on the fauna of India and adjacent areas. The Imperial Agricultural Research Institute (IARI), Pusa; the Imperial Veterinary Research Institute (IVRI), Mukteswar; the Imperial Forest Research Institute (now FRI) at Dehra Dun; the Indian Lac Research Institute, Ranchi; the School of Tropical Medicine, Calcutta; and the All India Institute of Hygiene and Public Health (AIIHPH) were all established during the first four decades of the present century, each one being engaged in a broad area of research and investigation incorporating zoological research as a part of activity. Likewise, the universities at Agra, Aligarh, Banaras, Bombay, Calcutta, Lucknow, Mysore, Nagpur, and Osmania University started courses in zoology during this period. With this tremendous amount of activity a distinct trend of work emerged.

As noted earlier, varied ecological conditions of the country invariably led to further faunistic studies. Simultaneously, research on other sub-disciplines of zoology made significant progress. The works on distribution, morphology,

and life cycles of many groups of animals like Mollusca (Annandale, Prashad, Rao); Oligochaetes (Stephenson, Gates); Decacpod Crustacea (Wood-Mason, Alcock, Kemp, Chopra); and fish (Annandale, Chaudhuri, Hora, Mukerji) were of primary interest in the first forty years of the current century. During the same period, through sustained interest in fresh-water and brackish-water fauna, Annandale made perhaps one of the most spectacular series of contributions on Porifera, Coelonterata, Mollusca, Crustacea and their habitats, besides his much quoted works on the Ganga-Mahanadi drainage system.

Major Trends of Research: Research on the morphology of animal forms resulted from the work of the university system. The teaching of zoology, largely based on examples from abroad, sometimes contributed little to help the understanding of animal life in the country. A large number of papers on the morphology of Indian animal species and, later, publication of memoirs on the commonest types of fresh-water and marine animals of India under the editorship of K. N. Bahl filled up these gaps. The morphological researches on helminthes, biological investigation on Polychaeta, Urochordata, and Chaetognatha received attention along with considerable work on Arthropoda, specially Insecta. Even the obscure myriapod fauna of India received attention. The discovery of one of the new genera of Indian animals, *Typhloperipatus*, in Abor Hills is still considered a valuable contribution.

The interest in general fauna, however, was the major result of investigation. The Bombay Natural History Society organized a survey of avian and mammalian fauna of the region. The marine survey started in 1884 was interrupted during the war years of 1914-18. Even when resumed after the war, it remained restricted to fewer operations by the *Investigator*. The exploration of shore and littoral fauna resulted in new data from salt lakes, estuaries, brackwaters of Bengal, Orissa, Andhra Pradesh, Tamil Nadu to Kerala, and Goa. A large number of research publications resulted from the above three major programmes of work. The fauna of such phyla as Protozoa, Coelonterata, Platyhelminthes, Brachiopoda, Polyzoa, Sipunculoidea, Pycnogonida, Echinodermata, Crustacea, Mollusca, Tunicata, Cephalochordata, and Pisces of the Indian region became known gradually through marine survey and programmes on littoral fauna.

During the same period entomological and arachnological research yielded valuable information on insects like Diptera, Coeloptera, Hymenoptera, Hemiptera, Odonata, Orthoptera, Thysanoptera, Ephemeroptera, Trichoptera, Neuroptera, Isoptera, Anopleura, Siphonoptera, and Spidera. The role of insects as pests of crops and forest plants and trees, vectors of diseases like malaria, and also as producers of lac, honey, and silk, was the subject of intensive research. Subjects like herpetology, ornithology, and mammology continued to receive additional support. Major contributions on the zoology of Indian

vertebrata were published during this period. Srinivasa Rao, as stated earlier, provides a detailed account of the progress of zoology including its sub-disciplines in his article published in *The Progress of Science in India during the Past Twenty-five Years*. In a text of sixty-eight pages followed by a fourteen-page bibliography, he cites 684 select references to papers on protozoology (20), marine zoology (98), helminthology (78), conchology (18), carcinology (22), entomology (110), arachnology (21), myriopoda (8), ichthyology (55), herpetology (21), ornithology (15), mammology (16), morphology (185), and cytology (17). The list, even though not complete, is indicative of the trend of research in different sub-disciplines of Indian zoology and the output thereof during a twenty-five-year period (1913-38). The research on morphological aspect shows a positive upward trend accounting for 185 out of 684 papers on the subject, while studies on cytology appeared to have just started.

According to a Government of India notification of 1 July 1916, the Zoological Survey of India (ZSI) was established with the following objectives and with Dr Nelson Annandale as its first director:

> 'It will be the duty of the Zoological Survey to act as guardians of the standard zoological collection of the Indian Empire and as such to give every assistance in their power both to officials and to others, in the identification of zoological specimens submitted to them, arranging, if requested to do so, to send collections to specialists abroad for identification in cases in which no specialist is available in India. The Survey will also obtain the fullest possible information about the systematic and geographical zoology of the Indian Empire and will place this information at the disposal of inquirers. It will not, however, interfere in any way with private enterprise in zoological matters or with the scientific work of other Imperial or Provincial Government departments.'

After a very fruitful and rewarding career Annandale died in 1923. The scientists of ZSI did some major work between 1923 and 1926 in diverse areas like oyster culture (Baini Prashad), crabs of rice fields (S. W. Kemp), fishes of Siam (S. L. Hora), animals in water supply system and their control at Pulta, West Bengal, India, and also in similar schemes in Sri Lanka and Burma. Collaboration with the fishery department in Tamil Nadu, development of fish hatcheries in Bihar and Orissa, excavation of prehistoric animal remains in collaboration with the Archaeological Survey of India, etc. constituted other major areas of practical work. Development of shell fisheries in the Andamans and investigation of the vectors of tropical diseases during 1929-32 indicated the scope of practical application of zoological research for the benefit of the human society. The scientists of ZSI also made significant contributions in leading an expedition to the South Seas for whale fisheries development (S. W. Kemp), Oxford University expedition to British Guiana in South

America (R. W. G. Hingston), and John Murray oceanographic expedition to the Arabian Sea and Persian Gulf (R. B. Seymore-Swell). Seymore-Swell was Surgeon-Naturalist of the Marine Survey of India and later, while this post was transferred to ZSI, worked as its Director till 1934.

As mentioned earlier, K. N. Bahl's *Indian Zoological Memoirs* were based on the study of marine types from the Indian coast. But in spite of repeated demand for establishing a marine biological station in India, only two marine zoological research centres could be founded till 1938, one at Madras maintained by the University of Madras and the other at the Gulf of Mannar maintained by the Madras Fisheries Department.

During 1900-40, sixty-seven fauna volumes were published, by far the largest number in a given period of time, dealing with Protozoa, Porifera, Nematoda, Cestoda, Annelida, Mollusca, Insecta, Arachnida, Reptilia, Aves (second edition), and Mammalia (second edition).[19] Of these forty-three volumes alone dealt with different groups of Insecta.

An analysis of the later development of zoology since 1940 can now be made by studying its advancement through higher educational facilities, correlation with research funding, its transgress into multidisciplinary research, major thrust areas of works, and trends of publication as output of accelerated activities and institutional support. Ghosh (1984)[20] while tracing the development of zoology in India during the last fifty years (1934-84) broadly outlined the details on the above subject.

Higher Education: Till 1933 eight universities in India were having facilities in post-graduate studies in zoology. During the last fifty years, thanks mainly to the organized activity of the University Grants Commission and support through the six five-year plans, a number of universities were established. Today out of 136 universities eighty-five are offering facilities for higher studies in zoology, entomology, marine biology, aquatic biology, life science or biological science, etc. Taking an average of twenty to twenty-five students obtaining the Master's degree through these universities every year, India can be said to be producing as many as 1,800 to 2,000 trained manpower in the area of zoology per year. This may be taken as an index of growth and development of the subject at the base level.

The trend of higher education in zoology, as the overall expansion of the university system shows, reveals a tremendously upward support pattern. Coupled with these avenues opening up during the last five decades, India's binational and multinational educational and cultural exchange programmes

[19]See J. R. Ellerman's *Fauna of India, Mammalia* (2nd ed.), Vol. III, *Rodentia*, pp. 36-50.

[20]*Science in India—A Changing Profile*, ed. S. K. Mukerji and B. V. Subbarayappa (INSA, Delhi, 1984), p. 20.

have lent additional vital support for higher education and training in the subject abroad, specially after the 1950s. Individual efforts also yielded rich dividends, specially in universities in the U.S.A. and Canada. The exposure to a wide range of teaching and research all over the world also contributed towards later developments in the formulation of modern curricula, offering wider choice of courses and subjects, at least in a few centres of excellence, instead of a rigid compartmentalization. So by 1980, the subject of zoology in India at one centre or the other covered such diverse areas as limnology, ethology, comparative endocrinology, cell biology, gene physiology, biotechnology, neuro-biology, cellular and comparative physiology, molecular biology, wild life studies, and ecology and environment, besides entomology and fisheries.

This trend has of late opened up in a most desirable manner the concept of multidisciplinary studies. The traditional syllabi formulated in a rigid manner in the university system has also underwent a major change and incorporated elements of biometrics, cell biology, physiology, and ecology in the study of zoology.

The University Grants Commission, in collaboration with the Indian National Science Academy and the U.S. Smithsonian Institutions, organized a symposium in 1971 on 'Development of Environmental Studies in Indian Universities' which discussed teaching, training, and research in ecology and conservation and management of natural resources, besides other aspects. Subsequently an expert committee identified the following institutions to undertake teaching, training, and research in the following areas: Banaras Hindu University—Inland Ecosystem; Andhra University—Coastal Ecosystem; Kashmir University—High Altitude Ecology; BITS, Pilani, and Jodhpur Universities—Desert Ecosystem; Gauhati University—Mangrove, Marshland, Wild Life; Calicut University—Forest Ecosystem; Kerala and Cochin Universities—Marine Ecology.

A workshop was organized at the North Eastern Hill University, Shillong, in 1976, sponsored by UGC, to develop courses on wild life study which could be incorporated in college curricula in biological sciences to generate worthwhile projects in wild life studies. Later, a national seminar was held in the Indian National Science Academy in 1979 to review the ongoing programme of environmental education. As a result of these activities, Jawaharlal Nehru University opened a School of Environmental Studies in 1975. Poona University, Maharashtra; Awadesh Pratap Singh University at Rewa, M.P.; Cochin University, Kerala; and a number of other universities also formulated and opened courses in environmental studies, a major part of which involved different sub-disciplines of zoology. The latest of such courses has been opened in the University of Calcutta at M. Phil. level. With the establishment of a

Central Department of Environment in 1980, the demand for higher studies and research will obviously be on the rise.

Another area of higher education related directly to zoological studies which has been given increasing emphasis during the last fifty years, and more so during the last two decades, is marine biological studies. Universities located in the coastal regions like Orissa, Andhra, Tamil Nadu, Kerala, Gujarat, and Maharashtra have established separate departments to study marine sciences including marine biology. The University of Calcutta may be listed as the youngest member in this group. The National Institute of Oceanography at Goa established in 1963-64 under the Council of Scientific and Industrial Research (CSIR) has during the last twenty years made valuable contributions on biological oceanography involving survey of biological resources, coastal aquaculture, studies in phytoplankton, biology of ecosystem under different environmental stress, marine microbiology, and studies on marine fouling and wood boring organism. ZSI also established a separate Marine Biological Station at Madras (1973) and published valuable data of research investigation on several aspects of marine biology. Likewise, the Central Marine Fisheries Research Institute at Cochin developed into a national centre for study of not only marine fishes but also other marine forms like corals, sponges, coelenterates, and turtles. The establishment of the Department of Ocean Development by the Government of India in 1982 after the first successful Indian Antarctic expedition and the current emphasis on oceanographic studies, as seen at the Indian Science Congress in 1983, are a positive index of growth and development of marine biology in India, besides other sub-disciplines of zoology.

The pattern of higher education and the emphasis laid at the national level by the Planning Commission and the rational identification of responsibilities of the major departments have all culminated in a systematic funding of research projects. The Department of Environment has funded about 124 projects (including those under the Department of Science and Technology earlier up to 1980) under the Environmental Research Council (ERC) and Man and Biosphere (MAB) programme. At least 20% of these have been carried out in only the zoology departments of Indian universities or other zoological institutes. The Department of Science and Technology (DST), CSIR, the Indian Council for Agricultural Research (ICAR), the Indian Council for Medical Research (ICMR), UGC, PL-480 Fund of USDA, etc. have borne almost all cost of researches in zoology in recent times in both pure and applied aspects. The universities along the bank of the Ganges have now undertaken a co-ordinated programme on the survey of the most vital drainage system in the subcontinent under the auspices of the Planning Commission and the Department of Environ-

ment. The zóology departments of the participating universities are playing a vital role in this project.

The higher education pattern in India and abroad, opened up to the students of zoology during the last thirty years in different phases of development, led to correlated areas of research activities. The number of Ph.D. degrees awarded can be used as an index of research work carried out in the laboratories of agricultural universities and national institutions like ZSI, IARI, Central Inland Fisheries Research Institute, Barrackpore, Central Marine Fisheries Research Institute, Cochin, Virus Research Institute, Pune, and a host of other institutes under ICAR and CSIR. A sharp upward trend of research activity can easily be noticed at almost all the institutes named above in the subject of zoology and its sub-disciplines. This is largely due to the availability of trained manpower on the one hand, and an ever-increasing input in research and development activities of the science and technology sector noted in the Planning Commission documents for the sixth five-year plan and the approach papers for the seventh plan. The allocation under the science and technology components for education is Rs 1,420 million for the period 1980-85, an average of Rs 284 million per year, as against Rs 60 to Rs 70 million per year in 1978-79 and 1979-80. Similarly, the allocation under CSIR, DST, and Environment for the period 1980-85 shows an average of Rs 1,520 million per year as against Rs 860 million in 1978-79 and 1979-80. Likewise, the allocation for ICAR and FRI during 1980-84 is put at Rs 5,420 million, i.e. Rs 1,008 million per year as against Rs 688·2 million and Rs 871·7 million per year for 1978-79 and 1979-80 respectively. All these figures include the entire field of science, agriculture, and technology, and from the allocation to each of the above-mentioned agencies, a sizable amount, at least 10%, is funnelled for researches in different areas of zoology, which should be at least Rs 280 to Rs 300 million per year. However, the thrust areas have changed radically in the 1980s, as can be seen in the relevant Planning Commission documents. A list of the new areas of thrust is given below: (i) molecular biophysics and theoretical biology; (ii) molecular and cellular biology; (iii) developmental biology of multicellular system; (iv) neurobiology and mechanism of behaviour; (v) animal behaviour, ecology, and evolution; and (vi) biology of reproduction. Agencies like ICMR, DST, CSIR, UGC, TIFR, DOEn (ZSI, BSI, etc.) are identified as agencies (indicative but not comprehensive) concerned with the implementation of the projects.

On the other hand, considerable emphasis has been laid in recent years on applied biological sciences including genetic engineering, protection of endangered species, and preservation of genetic diversity and ecological balance for sustainable utilization of biological resources.

Development and Contribution of Major Institutions and Agencies other than

Universities: During the last fifty years, the major contribution in exploration, identification, and collection of basic data of faunistic resources has been made by ZSI which has grown enormously from one centre at Calcutta to sixteen located all over India, regionwise and ecological zonewise. ZSI with its 1200 staff members and single largest budget provision in zoological studies and research (current annual allocation over Rs 28 million) continues to contribute towards the knowledge of faunal resources of India. A total of more than 800 intensive surveys have been carried out by scientists of ZSI in all the States of the Indian region. The most-needed resumption of publication of the *Fauna of India* series in such group where no volume was published earlier and revision of the outdated volumes through the Fauna of India Project started anew from 1975 have already yielded rich dividend. However, since 1934, thirty-four volumes of *Fauna of India* (formerly of British India) on (i) Protozoa, (ii) Nematoda, (iii) Trematoda, (iv) Polychaeta, (v) Coleoptera (4 vols.), (vi) Diptera (2 vols.), (vii) Lepidoptera (3 vols.), (viii) Odonata (3 vols.), (ix) Orthoptera, (x) Homoptera (3 vols.), (xi) Arachnida (3 vols.), (xii) Reptilia (3 vols.), and (xiii) Mammalia (3 vols.) have been published and these along with the earlier volumes published since 1888 provide the most consolidated data on faunal resources in the respective groups. ZSI has also published a *State of Art Report* (1980): *Zoology* which can be treated as a basic document on the subject in India.

IARI also played a very important role in the sub-disciplines of entomological and nematological research involving economic crops. FRI likewise contributed towards the biological studies of the forest system, and produced valuable documents on forest insect pests of the Indian region. The Commonwealth Institute of Biological Control (CIBC), Bangalore, established after independence, is another organization which has been the focal centre of activity for investigations on parasites and predators and other biocontrol agents of pests of economic crops and forest plantations.

The Government of India set up a desert afforestation station in 1952 under the aegis of FRI which was later widened in 1959 and redesignated as Central Arid Zone Research Institute (CAZRI) with headquarters at Jodhpur. Scientists of this centre contributed towards the understanding of human-animal interactions in desert area, wild life in desert region and its management, physiological adaptation of animals in arid-zone, etc.

The National Institute of Oceanography (NIO) at Goa has been referred to earlier; but NIO scientists' utilization of the country's first research vessel, *R.V. Gaveshani*, which has made more than 101 cruises in the seas around India and the Indian Ocean, needs special mention. The material collected during these cruises contributed substantially towards our knowledge on primary productivity, planktonology, benthic biology, microbiology, distribu-

tion of marine organism and their interaction, etc. The directories on marine research projects, marine scientists, and training and education facilities in marine sciences in India, published by NIO, will indicate the development of study and research in marine biology. The successful missions to Antarctica carried out by the scientists of NIO and other agencies (1981-84) are landmarks in further research activities. NIO has three regional centres of research at Cochin, Bombay, and Visakhapatnam, each one of which is actively involved in biological oceanographic studies.

The Central Marine Fisheries Research Institute (CMFRI) at Cochin and Central Inland Fisheries Research Institute (CIFRI) at Barrackpore established during the last thirty-five years can perhaps be credited with carrying out sustained result-oriented projects on fisheries research, specially on conservation, utilization, and management aspects.

A separate directorate of Wild Life Education and Research was set up at FRI during the fifth plan period. Later, a Central Crocodile Breeding Management and Training Institute at Hyderabad was started and these two units have formed the nucleus of a National Institute, The Wild Life Institute of India, currently located at Dehra Dun. This was set up in 1982 with four major objectives, viz. training, research, publication, and consultancy, and as such will meet the demand of yet another area of study and research on zoology, i.e. on wild life.

A host of other renowned research institutes, many established after 1947, contributed most significantly towards the applied aspects of research in zoology. These include: Bhabha Atomic Research Centre (BARC), Bombay; Bose Institute, Calcutta; Central Drug Research Institute (CDRI), Lucknow; Central Food Technology Research Institute (CFTRI), Mysore; Central Potato Research Institute (CPRI), Simla; Central Rice Research Institute (CRRI), Cuttack; Indian Institute of Chemical Biology (IICB), Calcutta; Indian Veterinary Research Institute (IVRI), Izatnagar; Indian Statistical Institute (ISI), Calcutta; and School of Tropical Medicine, Calcutta. The areas of investigation covered in these institutes include molecular and cellular biology, endocrinology, virus-vector relationship, physiology of parasites, immuno-biology, biochemical aspects of pest management, teratology, and genetic engineering. The aforementioned scientific institutions and the activities of the agriculture, fisheries, and forest departments at the State level together have contributed to a great extent to the development of zoology in India.

Congresses, Symposia, Seminars, etc.: In the last fifty years a number of meetings of professional zoologists, either under a broad umbrella or in smaller specialized groups, were held. Such meetings, now being largely financed by special grants of Central and State Government agencies, have increased considerably

in recent years. The first all-India Congress of Zoology was held at Jabalpur in 1959 sponsored by ZSI under the auspices of the University of Jabalpur. Subsequently five such all-India Congresses were held at Varanasi in 1962, at Waltair in 1975, at Bodh Gaya in 1978, at Bhopal in 1980, and at Gwalior in 1983. At each of these Congresses papers of major sub-disciplines of zoology were presented. Mention may be made of other agencies, viz. the Congress of Parasitology, first held in 1968 at Baroda and followed by four others; the Congress of Helminthology in 1976 at Bhopal; and the Congress of Cytology held later.

However, the largest congregation of entomologists was organized at the symposium on Oriental Entomology at Calcutta in 1975. This was followed by the second Oriental Entomology Symposium at Madras in 1977 and the third one at Trivandrum in 1984. A specialized symposium on 'Insects and Environment' at Delhi in 1977; a workshop on 'Advances in Insect Taxonomy in India and the Orient' at Manali in 1979; a workshop on 'High Altitude Entomology and Wild Life Ecology' at Solan in 1979; and a workshop on 'Recent Trends of Aphidological Studies' at Bhuvaneswar in 1976 reflect the trend of specialization and also document the available results of investigation.

During the last ten years other important findings in specialized fields of zoology in India maybe seen in the contributions to the symposium on 'Ecology of Animal Population' held at Calcutta in 1978 and the symposium on 'The Host as an Environment' held at Calcutta in 1980. A broader trend of research may be traced in the symposium on 'Modern Trends in Zoological Researches in India' held at Calcutta in 1976.

The Planning Commission has identified the Central Marine Fisheries Research Institute as the national data centre for marine fishes. As a result, a national workshop on 'Acquisition and Dissemination of Data on Marine Living Resources of Indian Seas' was held at Cochin in 1982, which has opened up the potentiality of data processing by the use of computer and other modern technologies. Similar technology is also going to be utilized for Environment Information Service (ENVIS) under the Department of Environment, Government of India, for which appreciation courses are held currently. The data related to zoological sciences will be sent through a Distributed Information Centre (DIC) to be located at ZSI, Calcutta, to the Central Information and Retrieval System at DOEn, New Delhi. On the marine science, an international seminar on estuaries was held at Dona Paula, Goa, in 1981 where the physics, chemistry, biology, geology, etc. of a given ecosystem were discussed from an interdisciplinary viewpoint. Earlier, in 1977, the first International Symposium on Avian Endocrinology was held at Calcutta. The International Congress of Genetics was held at New Delhi in 1982.

A large number of seminars and symposia have been held since 1976-77 on the subjects of environment, conservation, ecology, and wild life. A national congress on environment was held at New Delhi in 1982. The third conference of the contracting parties to the convention on International Trade on Endangered Species of Wild Fauna and Flora (CITES) was also held at New Delhi in 1981.

These seminars and symposia were largely initiated by a host of scientific societies, among which mention may be made of the following: Zoological Society of India; Zoological Society, Calcutta; Helminthological Society; Indian Society for Soil Biology and Ecology; Wild Life Preservation Society of India; Ichthyological Society; and Association for Advancement of Entomology. These activities contributed to the mutual exchange of ideas and helped development of zoology in the country.

Research Publications: A direct correlation of higher educational opportunities, establishment of new universities, research institutes, and State and Central Government agencies, along with the ever-increasing funding for research may be established by a sample survey of the publications on zoology from India. The progress report on zoology and entomology in *A Decade of Science* (1963-72) alone contains more than 2,000 references to research papers published by scientists from Indian institutes. The annual reports of the premier zoological institute, ZSI, shows a total of 2,000 titles of papers published by scientists of ZSI during 1960-80. A number of new journals were initiated during the last fifty years, viz. *Bulletin of the Zoological Survey of India* (1977), Calcutta; *Indian Fisheries Bulletin* (1954), New Delhi; *Indian Journal of Entomology* (1939), New Delhi; *Indian Journal of Experimental Biology* (1963), New Delhi; *Indian Journal of Fisheries* (1954), New Delhi; *Indian Journal of Helminthology* (1951), Lucknow; *Indian Journal of Marine Sciences* (1972), Delhi; *Indian Journal of Nematology* (1971), Delhi; *Indian Journal of Zoology* (1960); *Journal of Bengal Natural History Society* (1939), Darjeeling; *Journal of Indian Fish* (1971), Bombay; *Mahasagar* (1968), Goa; *Matsya* (1975), Madras; *Occasional papers—Zoological Survey of India* (1977), Calcutta; *Oriental Insects* (1967), Delhi; *Entomon* (1975), Trivandrum; *Proceedings of the Zoological Society* (1948-49), Calcutta; etc. These are largely devoted to various sub-disciplines of zoology but a host of other new journals from India also offer new avenues for publishing results of investigations involving more than one area of the science, specially in the experimental aspects of research.

It may be worthwhile mentioning that ZSI, the largest single institution of zoology, alone has increased publication of regular or occasional titles (like *Memoirs*, *Records*, and *Fauna*) from three to ten to cope with the ever-increasing demand for publications.

H. Srinivasa Rao's review of the progress of zoological research in India

in the Silver Jubilee volume of the Indian Science Congress in 1938 refers to only 684 research papers on zoology published up to 1938 of which 368 papers were written by authors from other countries and 316 by Indian scholars. When this figure is compared with the 2,000 references in the report on the progress of zoology in *A Decade (1963-72) of Science in India* one can form an idea of the trends of progress in education, research, and publications on zoology in the country. The proceedings of the Indian Science Congress also provide further data regarding the gradual upward trend of research and investigations. During the period between 1934 and 1955 the number of abstracts printed for the section on zoology and entomology never exceeded 100; but between 1955 and 1982 the number varied from 100 to 329, and a total of over 6,700 papers were presented in the zoology and fisheries sections of the Indian Science Congress during the last fifty years.

Publications like *Indian Zoological Memoir* on Indian animal types, mentioned earlier, and the series of monographs and supplements on specific subject areas further indicate newer areas of work. A study of *Bibliography of Indian Zoology*, started in 1958 by ZSI, can perhaps provide the most extensive references to research works during the last twenty-five years.

Progress in Selected Areas of Work: A sample survey of work in some selected areas during the last fifty years may be made here to highlight the progress in specific fields. In vertebrate zoology an overall development of teaching and research can be noted but, considering the unique assemblage of vertebrate fauna, much remains to be done in areas of applied, behavioural, and ecobiological studies on endemic forms. The largest contribution can be noted in ichthyology through the school of S. L. Hora and his co-workers. It was in 1937 that Hora proposed 'Satpura hypothesis' to explain anomalies in the distribution of some fresh-water fishes in the Indo-Malayan region, which was discussed in an extensive manner at a symposium held under the National Institute of Sciences of India in 1949.

The study on Amphibia and Reptilia was supported with the publications, *Fauna of India: Serpents* by Malcolm Smith (1943) and *The Snakes of India* by Deoras. The most significant work on the biology of Reptilia also started in the period under review through the Crocodile Breeding and Management Project launched in 1976. All the three species of gharial, mugger, and saltwater crocodile have been covered under this scheme, a total of twenty-six centres having been set up all over the country. A crocodile bank with a scheme of biological study and captive breeding was set up in Madras very recently. Work on fresh-water tortoises and marine turtles has been initiated during the last five years. Although there has been no comprehensive project on the biology and faunistic character of the amphibians, mention may be made of the work on their urinogenital system and the use of amphibians in determining pregnancy

in the human female as well as some scattered publications on embryology, frog-breeding for export, and some faunistic studies from high altitude and north-eastern India and western India.

The ten-volume series entitled *Handbook of Birds of India and Pakistan* by Salim Ali and S. Dillon Ripley; *A Synopsis of Birds of India and Pakistan* by S. Dillon Ripley; and *Birds of Eastern Himalaya* and *Indian Hill Birds* by Salim Ali contributed greatly to the understanding of the ecology, distribution, biology, and related areas of ornithology in India. Several studies on the endangered species of birds (and migration of birds through ringing operations) have been carried out including the one on the white-winged wood duck, black-necked crane, great Indian bustard, pheasants, etc.

The first two (new series) volumes on Mammalia under the *Fauna of India* series were published in 1939 and 1941, covering the primates and carnivores; the third, written by Ellerman on Rodentia, was published in 1963. Prate's *Book of Indian Animals* was published in the late fifties. Faunistic accounts of different regions of India, viz. Assam, Rajasthan, Jammu and Kashmir, the Western Ghat, and the Andaman and Nicobar Islands, appeared during this period. The survey and biological studies of non-human primates increasingly found support from the Department of Science and Technology, and a Primate Research Centre under the Indian Institute of Science has been set up. A large number of contributions on Indian mammals and birds including description of new taxa could be noticed in the *Journal of the Bombay National History Society*, in addition to the publications of ZSI. The Society while celebrating the centenary in 1983-84 published *A Century of Natural History* and *The Book of Indian Reptiles*.

It may be added that the Indian Board of Wild Life was also set up in 1952 to aid and advise the Government on matters relating to wild life conservation in India. The Wild Life (Protection) Act 1972 provided additional measures for conservation along with the establishment of forty-four National Parks and 207 sanctuaries covering 87,735 sq. km. This offered an ideal setting for wild life studies in undisturbed natural conditions and resulted in a number of research papers on ethology, ecology, and behaviour of animals as well as in population studies of animals—specially those from the list of 253 species of mammals, birds, amphibians, reptiles, crustaceans, and insects protected under the Act. A total of forty-four zoological gardens mostly developed or set up during the last five decades also provided opportunities for behavioural studies of animals in captivity.

The study and research in the areas of invertebrate zoology, specially in entomology, was traced by B. C. Basu in his address to the thirty-seventh Indian Science Congress in 1950. Entomological study and research can perhaps be marked as the single largest area of work in Indian zoology during

the last fifty years. A number of invertebrates have been extensively studied. Special mention may be made of the parasitic protozoans, helminths, ticks, and mites, which have been studied from the faunistic, distributional, and applied experimental research points of view. Sustained research in endocrinology (Calcutta, Delhi, BHU), parasitology (Calcutta, Burdwan, Lucknow, Allahabad, Waltair, Kashmir), cytogenetics (Calcutta, Kalyani, BHU), limnology (Madurai, Kerala, NEHU), entomology (Calcutta, Agra, Delhi, Kanpur, Allahabad, Ludhiana), marine biology (Berhampore, Waltair, Madras, Kerala), or in other specific areas, involving both vertebrate and invertebrate forms, was carried out during the last five decades.

CONCLUSION

The present review has been prepared to focus the overall developmental process by noting the early history leading to the introduction of zoology as a subject in almost all major universities, the generous funding of research projects, change of thrust in the area of work in recent years, infrastructural support through new journals and other publications, contributions from new national institutes and agencies, etc. India has seen the development of study of animals as an accepted branch of science in its own classical way. The period of foreign rule opened up avenues for intensive work, largely carried out by naturalists from abroad but obviously supported by our countrymen till the later part of the nineteenth century. Since then there have been signs of a changing profile in which Indian scientists and naturalists alike contributed increasingly and immensely to the development of the subject. The foundation thus laid will undoubtedly usher in a new era by the turn of the twentieth century.

23

MEDICAL SCIENCES

THE practice of both Āyurvedic and Unani (Gracco-Arab) systems of medicine was quite common in India during the medieval period and it continued to be popular up to the first two decades of the nineteenth century. The art of healing was mostly confined during this period to the *vaidyas* or *kavirājas* of the Āyurvedic school, and *hakims* of the Unani system. While Hindu patients usually turned to the former, the bulk of the Muslim population preferred the latter. Elementary surgical operations like bone-setting were performed by quacks, chiefly village barbers. There are records of blood-letting and cataract operations being practised. The indigenous systems of medicine are still practised in India, though not as widely as before, with modern innovations.

I

The establishment in 1822 of a school of native doctors in Calcutta was the first attempt of the British authorities to train Indians in the elements of the European system of medicine and surgery with a view to filling up subordinate ranks in the army medical establishments. Consequent upon the demands of a section of Hindus and Muslims for the training of physicians in their own systems, classes were opened in 1826 at the Government Sanskrit College, Calcutta, and the Calcutta Madrassa to teach the Āyurvedic and Unani systems respectively. The efforts of these institutions met with varying degrees of success. In the meantime, a bitter controversy arose between the orientalists and the Anglicists, ultimately resulting in the victory of the latter and adoption by the Government of the policy of imparting education in European arts and sciences through the medium of English. The School of Native Doctors along with the medical classes at the Sanskrit College and Calcutta Madrassa was abolished, and the Medical College of Bengal was set up in 1835. The council of the Asiatic Society of Bengal, with the only Indian participant, Babu Ram Comol Sen, played an important role in the establishment of this Medical College, the first of its kind in India. The newly-established Medical College adopted the principles and practice of medical science strictly in accordance with the European system and started teaching Indian students in English.

THE PIONEERS

Madhusudan Gupta, a pandit in charge of the Āyurvedic department of

MADHUSUDAN GUPTA, FIRST INDIAN TO HAVE DISSECTED A DEAD BODY

MEDICAL COLLEGE OF BENGAL,
INSTITUTED
IN THE YEAR OF THE CHRISTIAN ERA,
1835:
CORRESPONDING TO THE BENGAL ERA,
1242:

We the undersigned having fully and carefully examined Modhoosoodun Gupta of Boydobatty on the 26th of November 1840 do hereby certify that he possesses an intimate knowledge of Anatomy, Physiology, Chemistry, and Materia Medica, and that he is sufficiently versed in the Principles and Practice of Medicine and Surgery, to qualify him for holding public Medical employment or for commencing independent practice We have further received satisfactory proof of his diligence and good conduct, during his education at the Medical College of Bengal.

مایانکه ممتحنین طلبهٔ مدرسه طبیه بنگاله هستیم تاریخ بست ششم ۲۶ ماه نومبر سنه ۱۸۴۰ء امتحان مدهو سودهن گپت ساکن بیدیا باٹي ـ بتحقیق تمام و غور مالاکلام بانواع مختلفه و طرق متعدده گرفتیم لهذا حسبةً لله گواهی می دهیم بر این معنی که طالب العلم مذکور در علوم تشریح و طبائع موجودات و ترکیب و تحلیل مرکبات و امزجه ادویه مفردات و مرکبات وغیره مهارتي شایسته و استعدادي بایسته بهم رسانیده است و نیز از اصول و ضوابط عام طبابت و علم جراحت و عمل آن چندانکه باید و شاید وجه احسن واقفیت و اطلاع حاصل نموده قابلیت انجام عهده طبابت و متعلقات آن بعلاقه از علاقجات عمالی محروسه سرکار فیض اثار و لیاقت انصرام پیشه خواه داخل علاقه کمپني باشد یا خارج آن میدارد و این شخص می تواند که قرار واقعي بمعالجه پردازي اوقات بسري خود نماید و حالات تندهي و جانفشاني او تا زمانیکه در مدرسه طبیه بنگاله تربیت می یافت نزد مایان به ثبوت واقعي رسیده است *

আমরা মনোযোগ পূর্ব্বক সম্যক প্রকারে ইং ১৮৪০ শালে নবম্বর মাসের ২৬ দিনে বৈদ্যবাটী নিবাসি শ্রীমধুসূদন গুপ্তের পরীক্ষা লইয়া তাহাকে প্রশংসা পত্র দিতেছি ইনি শারীরবিদ্যা দ্রব্যতত্ত্বজ্ঞান দ্রব্যগুণ ও কিমিয়া বিদ্যা এই সকল বিষয়েতে বিশেষ নিপুণ এবং ঔষধ প্রস্তুত করণে ও তদ্ব্যবহারে আর অস্ত্রবিদ্যা ও চিকিৎসাকর্ম্মে প্রকৃত উপযুক্ত হইয়াছেন ইহাতে ইনি রাজকীয়চিকিৎসক সাধারণের পদপ্রাপ্ত হইতে পারেন এবং সহকারব্যতিরেকে স্বয়ং তৎকর্ম্ম নির্ব্বাহ করিতে পারেন ॥

উক্ত ব্যক্তির বাঙ্গালা দেশীয় চিকিৎসাবিদ্যালয়ে অধ্যয়নারম্ভাবধি একালপর্য্যন্ত সুশীলতায় ও পরিশ্রমেতে আমরা সন্তুষ্ট হইয়াছি ॥

Signed by—

ASSESSORS

S. Nicholson —Surgeon General Hospl.
A. Egerton, M.D.—Presidency Surgeon
H. P. Mercer—Marine Surgeon
Illegible—Presidency Surgeon
W. Cameron—Presidency Surgeon
D. Stewart—Supt. Genl. Vaccination
Walter Raleigh—Surgeon Nat. Hospl.

TEACHERS

N. Wallich, M.D.—Professor of Botany
Charles Egerton— Ditto Surgery
H. H. Goodeve, M.D.—Ditto Anatomy and Medicine
W.B.O'Shaughnessy, M.D —Ditto Chemistry & Mat. Med.
R. O'Shaughnessy—Demonstrator of Ana.
David Hare—Secy. Med. College of Bengal

EXAMINERS

J. Grant—Apothecary General
Thos S. Wise, M.D.—Secy. Genl. Com. P.I.
Edward Ryan—President Com. of P. I.
G. A. Barbley Secy. to Govt., Genl. Dept.

FACSIMILE OF THE CERTIFICATE AWARDED TO MADHUSUDAN GUPTA

the Sanskrit College, was transferred to the Medical College and given training in the new system. He was the first Indian to dissect a dead body and as such his is a name of special note in the history of medical education in this country. With a scientific bent of mind, he had done the dissection risking social excommunication. This epoch-making event was greeted by gun-fire from Fort William, Calcutta. Madhusudan Gupta received a diploma for practice in medicine in 1836 and was, again, the first Indian to have this honour. A ward with twenty beds and an out-patients' department were established in 1838 as the nucleus of the first hospital attached to the Medical College. Within another two years a hospital with 100 beds was constructed on the college grounds. A group of four Indian students, graduates of this college, was sent to England in 1844 for higher studies and training in medicine. Two other medical institutions had been set up, one in Bombay and the other in Madras, about the time of the establishment of the Calcutta Medical College. Professors of great learning and those skilled in research were recruited for them from England and Ireland. During the latter part of the nineteenth century twenty-eight medical schools with shorter courses were set up in different parts of the country.

Opportunities for Research: Although facilities for pathological study were too often wanting, India offered to the professors and medical men from the West great opportunities for original research and discovery. It is no wonder that distinguished workers like W. W. Haffkine, Ronald Ross, Robert Koch, Leonard Rogers, and others chose this country as their field for carrying on investigations in collaboration with Indian assistants. Haffkine came to Calcutta in 1892 and started his research work on cholera in collaboration with his friend Simpson in a small laboratory. Within two years' time he invented anti-cholera vaccine for successful prevention of this scourge. In this important work he was substantially assisted by his four Indian colleagues: Choudhury, Chatterjee, Dutta, and Ghause. In 1896 he was invited by the Government of India to investigate the cause of epidemicity of bubonic plague in Bombay. In a small laboratory attached to the Grant Medical College he worked untiringly and was able to prepare an anti-plague vaccine which still bears his name. He was the first to be inoculated by this vaccine. On 10 January 1897 Bannerman submitted a report about the efficacy of Haffkine's anti-plague vaccine and various other successful investigations.

Ronald Ross came to Calcutta as an army doctor almost at the same time Haffkine was busy with his anti-cholera vaccine. Ross started his investigations on the aetiology and causation of malaria, a fell debilitating disease very much prevalent in this country from time immemorial. He established the association of malarial parasites with a certain type of mosquitoes and demonstrated it at a meeting of the British Medical Association in 1898 by an experiment. The experiment showed that when a particular species of mosquito fed upon the

blood of plasmodium-infected birds, the parasite closely resembling malarial parasite entered the stomach wall of the insect, grew, and sporulated there. The resulting sporozoites subsequently entered the salivary gland of the insect which then was capable of infecting other birds.

STUDY OF TROPICAL MEDICINE

In the course of his address on the occasion of the seventh anniversary of the Asiatic Society, Sir William Jones, its founder-President, spoke of crystalline arsenic as a 'Hindu cure' for the treatment of elephantiasis and recommended the same for trial by European doctors. Two years later, in 1793, he mentioned Mellori as a fruit both palatable and nutritive to a high degree and advocated its use for the poor people of India. Earlier, in 1790, he published *A Treatise on the Plants of India* containing a concise and accurate classification of these plants and their medicinal uses. For this work William Roxburgh, the famous botanist, paid him a great tribute by naming the indigenous Aśoka tree after Jones: *Jonesia aśoka.*

From the beginning of the nineteenth century, following the writings of Sir William Jones in a memoir named *Botanical Observations of Select Plants,* there were some efforts to collect information regarding medicinal plants growing in different parts of the country. Thus were prepared the *Catalogue of Medicinal Plants* by John Fleming in 1810; *Materia Medica of Hindusthan* in 1813; and *Flora Indica* by Roxburgh in 1820. Alexander Csoma de Koros, famous Hungarian adventurer and orientologist, brought to Calcutta from Tibet in 1831 many rare manuscripts and also a long list of medicinal plants used there. O'Shaughnessy published in 1844 the *Bengal Pharmacopoeia,* the first of its kind dealing exclusively with the properties and uses of medicinal plants of Bengal. In 1868 under the able editorship of Waring, the *Pharmacopoeia of India* was published, which for the first time recorded the value of indigenous medicinal products on modern lines. Many important local drugs were thus officially recognized with a view to their eventual adoption in the *British Pharmacopoeia.* A supplement was added to it a year later by Mohideen Sheriff, which included a large number of household drugs and drugs used by local practitioners. He also wrote the *Materia Medica of Madras* edited and published posthumously by Hooper.

In the last quarter of the nineteenth century U. C. Dutt's translation of Sanskrit materia medica brought into prominence the drugs used in the ancient system of Hindu medicine and even now current in India to some extent. In 1883 was published Fluckiger's and Hanbury's *Pharmacopoeia Indica* under the joint editorship of Warden and Hooper. This book contains a lot of information regarding the uses of indigenous drugs in Indian and western medicine. The most elaborate work of all is *A Dictionary of the Economic Products of India*

published in 1895 by Sir George Watt, which was compiled with the help of a large team of Indian workers. These books form the basis of indigenous drug research in this country from the beginning of the present century up to recent times.

DISEASES AND REMEDIES

Cholera: Indian workers were more or less in the background in the field of medical research throughout the nineteenth century as also during the first quarter of the twentieth. The cholera vibrio was discovered by the German scientist Robert Koch while on a casual visit to Calcutta (1905). There are, however, several instances of Indian workers actively assisting in important medical research. Leonard Rogers, a professor of the Calcutta Medical College, successfully worked out the treatment of cholera by hypertonic saline injection (1913), a work in which he was assisted by Chatterjee, Banerjee, and others. Cholera research in its various aspects has gone on since in different parts of India.

D'Herelle (1927) found that bacteriophage played an important part not only in the epidemiology of cholera but also in the cure of the disease. He prepared an active bacteriophage which was reported to have yielded good results after its use in the Punjab. He also claimed that natural recovery in cholera was due to the development of bacteriophage in the bowels. The phage, he pointed out, either destroyed the cholera vibrios or converted them into harmless non-agglutinating vibrios. This work was continued successfully by Asheshov and his co-workers (1933). Later, Ahuja (1935) and Taylor (1936) found agglutinable vibrios from healthy individuals in an endemic area in Bengal and also from the water of non-endemic areas in Kohat, far from Bengal, which developed the biological character of true cholera vibrios, including agglutinability, after six months of subculture.

Kala-azar: Important research was done on kala-azar which was previously incurable and took a heavy toll of lives in Bengal and Assam. Shortly after the discovery of the specific parasite, Rogers (1904) succeeded in cultivating the Leishman-Donovan bodies and demonstrated the flagellate form of the parasite in culture. He devised a method for the diagnosis of kala-azār by flagellate culture from the peripheral or splenic blood in N.N.N. medium. U. N. Brahmachari (1917) found not only increased amount of globulin but also the presence of an easily precipitable globulin in the serum of kala-azar patients, and formulated the earliest methods of serum diagnosis tests for the disease, viz. ***globulin opacity test*** and ***globulin ring test***. On the same basis, Napier later invented the ***aldehyde test*** and Chopra the ***urea-stibamine test***.

As to the treatment of kala-azar, Rogers (1916) advocated intravenous injection of antimony tartrate. The suggested dose was, to begin with, ½-1 cc.

of 2% sol., rapidly to be raised to 3-4 cc. of repeated injections every two or three days. But this was painful and led to fever with *rigor* immediately after the injection. To improve upon this, Brahmachari (1922) synthesized a series of antimonials, notable among which was a pentavalent organic antimonial named urea-stibamine, possessing remarkable therapeutic properties. This wonder drug was mainly responsible for the eradication of kala-azar from Bengal and Assam. Chopra, Gupta, and David (1927) showed that the amount of precipitate formed by treating solutions of various pentavalent antimony salts with the sera of kala-azar patients was in proportion to their therapeutic value and that among them urea-stibamine yielded the largest amount of precipitate. It was therefore by far the best drug. In 1922 U. N. Brahmachari also reported the presence of L. D. bodies in nodular growths found on the body of a patient cured of kala-azar by antimony treatment. This peculiar skin condition of the disease, called dermal leishmanoid, was usually found in a certain percentage of cases about two years after their cure. The histopathology of dermal leishmanoid was studied by Shortt as well as by P. Brahmachari. Studies and researches on kala-azar are still in progress with Government financial assistance by a special unit at Patna.

Pulmonary Eosinophilia: The credit of recognizing a new disease, tropical pulmonary eosinophilia, goes to Roy and Bose (1919) who first noticed that asthma-like symptoms with leucocytosis and eosinophilia were cured by intramuscular injections of soamin.

Plague: Mention has already been made of Haffkine's plague vaccine which showed excellent result in respect of immunization. Later, useful work on the preparation and standardization of plague vaccine was done by Naidu (1927), Jung (1929), and others at the Haffkine Institute, Bombay. The same workers in collaboration with Kamakaka (1930) prepared a potent specific anti-plague serum. Sokhey (1938), too, evolved quantitative methods for measuring the virulence of different strains of plague and the protective value of the plague vaccine. Earlier, an Indian plague commission had investigated the cause of the disease and found that plague was primarily a disease of rats and that it spread to man through the bite of rat-fleas. Thus rat-fleas were held responsible for transmission of the disease. Rothschild, Hirst, Cragg, and others studied the role of different species of fleas in the epidemiology of plague. Subsequently, the entire knowledge about the plague bacillus, control of the disease by vaccine, methods of its treatment, and lines of surveillance were established by S khey and Seal. Their work eventually led to the eradication of plague fr m India. It may be mentioned in this connection that no case of human plague has been reported in this country since 1967. Nevertheless, a plague surveillance unit works at Bangalore as one of the many research projects financed by the Government of India.

Malaria: Following Ross's monumental work on transmission of malaria by mosquitoes, many workers like Christophers (1916), Sinton (1917), Barraud (1923), James (1927), and Iyengar (1931) did valuable research on the entomological aspect, specially with reference to the identification of the Indian species of carrier mosquito, adults and larvae. Knowles and Das Gupta (1932) clarified many important points by their valuable contribution on the parasitology of man and monkey. Reference may be made to the cytological and splenectomy experiments of Krishnan and others (1933) with special reference to the role of the reticuloendothelial system (especially spleen) in malarial immunity. The work of Brahmachari and his assistants (1932-33) on the chemotherapy of quinoline compounds for malaria is also worth mentioning. A comparative study of the action of the two anti-malarial drugs, viz. atebrin and quinine, was made at the School of Tropical Medicine, Calcutta. Atebrin was found to be acting directly on the parasites whereas quinine seemed to have an influence through some defence mechanisms of the body. Brahmachari and Sen (1925) also noted that during active haemolysis in black water fever the greatest amount of haemolysis took place in the liver.

Epidemic Dropsy: The cause of epidemic dropsy being a toxin in adulterated mustard oil was first suggested by Mitter and later confirmed by Sen through clinical observations. This was further corroborated by Lal and Roy (1937) in laboratory experiments in connection with epidemiological investigations of a few outbreaks of the epidemic in Bengal and Assam. The causative role of argemon (*Argemone mexicana*) in epidemic dropsy was advocated by Lal, while Seal's work related to its detoxication. As Shanks and De presented detailed studies on the pathology of epidemic dropsy, Chopra and Basu (1930) found that the tincture of ephedra was a useful remedy for the cardiac complications of the disease.

Leprosy: For the treatment of leprosy Rogers (1917) prepared a soluble sodium salt of the fatty acid of chaulmoogra oil hitherto used by mouth in Āyurvedic therapy, and administered it by intramuscular and intravenous injections with great benefit. Rogers and Ganguli also obtained good results from the use of sodium morrhuate. Muir (1927) found that esters of hydnocarpus oil were of great therapeutic value and advocated intravenous application of sodium hydnocarpate.

Although leprosy today is not an incurable disease as it was before independence, it is still a major health problem in various parts of India including the States of Andhra Pradesh, Orissa, Karnataka, Maharashtra, Tamil Nadu, and Bihar. In 1955 the Government of India undertook a national leprosy control programme. The same year saw the setting up of the Central Leprosy Teaching and Research Institute at Chingleput which trains medical and paramedical personnel, treats leprosy patients, and is recognized as a WHO regional

centre for certain investigations on leprosy. The latest research on leprosy was by B. R. Chatterjee, who for the first time successfully cultured *lepra* bacillus in an artificial medium.

Amoebiasis: The most notable advance in the treatment of amoebiasis was the introduction by Rogers (1913) of the intramuscular injection of emetine hydrochloride for the cure of amoebic dysentery, pre-suppurative hepatitis, and amoebic abscess of the liver. Ramaswamy Iyer, Ramachandra, Simonsen and co-workers (1926), and also Chopra and associates (1927) showed the efficacy of the active principles of *kurchi* bark in the treatment of dysentery. A compound preparation of the total alkaloids named *kurchi*-bismuth-iodide showed a great promise of efficacy and encouraging results were obtained with this preparation.

Rabies: In 1923 Shortt made a valuable investigation into the relative immunizing value of Kasauli and Paris strains of rabies-fixed virus, which is the basis of the current method of successful anti-rabies inoculation in India.

Snake Venom: Acton and Knowles (1912) observed that the antibodies in antivenene contained serum globulin and that these could be precipitated from immune goats' serum by 40% saturation with ammonium sulphate. Moitra and co-workers (1933) noted that with sodium sulphate at least a threefold concentration of antivenomous serum could be obtained. Venkatachalam and Ratnagiriswaran (1934) found that sublethal doses of the venom of the Indian cobra paralysed the motor end-plates, while with bigger doses animals died before the paralysis. Chopra and Chowhan (1934) observed that the paralytic action of the *Indian daboia* on the capillaries resembled that of histamine shock. Again, Chopra and co-workers (1935) found that the venom of *Echis carinata* had curare-like action on the nerve endings causing death.

Dengue: Shortt, Sanjiva Rao, and Swaminathan (1936) were pioneers in cultivating the viruses of dengue and sandfly fevers on the chorio-allantoic membranes of the chick embryo.

NUTRITIONAL RESEARCH

McCarrison at Coonoor (1923-24) was the pioneer in nutritional research in India. He showed that vitamin deficiency might produce a defective keratinization of the genito-urinary tract and give rise to stones in the bladder, a small focus of infection forming the nucleus. McCarrison (1928) also did a lot of work on the aetiology of goitre in India and opined that although iodine deficiency might contribute to goitre, it was not the cause of the malady. The causes were possibly dietetic deficiencies, especially deficiency of vitamin A, insanitary conditions, and water polluted with *goitre noxa*, which was found to be water-soluble and of a dual nature—with a hyperplasia-producing factor and an adenoma-producing factor. The former was counter-

acted by a well-constituted diet with iodine, while the latter was not. McCarrison also found soyabean and groundnut to be goitrogenic in the absence of vitamin A. He investigated the goitrogenic action of cabbage on rabbits. He found carrots, sprouted grams, and freshly-cut grass to be anti-goitrogenic. McCarrison also showed that spastic condition of the gastro-intestinal tract together with changes in Auerbach's plexus was common in animals given autoclaved diet. Guha (1931), while in England (with Birch), did valuable work on the nature of vitamin B_1 from the evidence afforded by its electrical transference. Special mention must also be made of his investigations on vitamin B_2, its source, stability, and chemistry. Guha (1932) was able to synthesize vitamin B_1 and 'Bios' by *Bacillus vulgatus.* Ahmed (1938) injected colloidal carotene intravenously into dogs and observed the formation of vitamin A from carotene in the reticuloendothelial system (spleen).

Harris and Ray (1933) developed a specific quantitative test with 2 : 6-dichlorophenol indophenol for estimating the vitamin C content of foods which they confirmed to be as accurate as the biological and spectrographic tests for the anti-scorbutic factor. They made an exceedingly useful contribution to the diagnosis of vitamin C deficiency by examining the ascorbic acid content of urine (less than 30-33 gm. of ascorbic acid per day). Swaminathan (1940) invented a very useful and accurate test for pyridoxin (vitamin B_6) in samples of food. Banerjee (1944) observed that the number and size of islets of Langerhans were increased in scorbutic guineapigs and the β-cells appeared to be degranulated. Mukherjee (1935) showed that insulin phosphotungstate and phosphotungstic acid were potent oral hypoglycaemics.

Nag and Banerjee (1931) found that vitamin A potency of hilsa liver oil was equal to that of halibut liver oil. Pal and Prasad (1934) showed by perfusion that insulin had a stimulating action on the vagus terminals and, as such, the heart was slowed down and blood pressure lowered, and that insulin was a direct antagonist to atropine. So insulin is now used by injection to get an increased secretion of gastric juice in cases of hyperacidity for diagnosis if it is associated with malignancy in the stomach. The same workers (1935) showed that intravenous glucose preceded by injection of a small dose of insulin might act as a very good cardiac stimulant. Pal and Prasad (1936) also demonstrated that Lugol's iodine solution slowed but at the same time augmented a normal frog's heart-beat; that thyroxine in small doses slightly accelerated the heart with diminished auricular complex but on prolonged action the heart became irregular with grouped beats; and that Lugol's iodine solution could remove completely this toxic effect and make the heart regular. Potassium iodide present in this solution is not responsible for this action.

INDIGENOUS DRUGS

The most outstanding medical research in India in the first half of the present century was in the field of indigenous drugs, some of which have found their place in the British and American pharmacopoeia. One such drug, *kurchi* (*Holarrhena antidysenterica*), has already been mentioned. Another notable one is *sarpagandha* (*Rauwolfia serpentina*) roots, the active principles and therapeutic properties of which were originally reported at a monthly meeting of the Asiatic Society of Bengal in March 1912. Chopra and co-workers (1933) showed that it was an effective sedative which brought down the blood pressure, particularly the diastolic. The active principle has since been identified as reserpine, and today it is used not only as one of the most effective hypotensive drugs but also as a good sedative to calm down excitable insanity cases. Similarly, Chopra (1930) showed that *isafgul* (*Plantago ovata*) was an excellent sedative in irritative conditions of the guts.

Mention has already been made of the various investigations in England by Guha and Ray in collaboration respectively with Birch and Harris. Subba Row (1942) was another outstanding researcher who worked in the Lederle Laboratories for the successful preparation of folic acid from liver extract. Folic acid is now used as a very efficacious remedy for certain types of intractable anaemia (microcytic) and sprue. Row was also associated with the preparation of the potent antibiotic Aureomycin.

Bhaduri and Bhandari (1941) invented a simpler and more economical test for the diagnosis of pregnancy by injecting the urine of women, missing one or more periods, in male frogs (*Rana tigrina*) and noticing spermatogenic activity as mature spermatozoa. This is now used as a sure pregnancy test. Chopra and Ghosh (1925) also found the efficacy of *Adhatoda vasica* as a good expectorant. Investigations in the hands of Chopra and Chatterjee (1927) proved *babuchi* (*Psoralea corylifolia*) to be useful in leucoderma. Nath and Choudhury (1945) showed that amellin, an active principle isolated from *mundari* (*Scoparia dulcis linn*), when injected daily into hyperglycaemic rabbits reduces blood sugar to normal, prevents tissue wastage, and causes better utilization of protein. With 20 mg. of amellin daily, patients even with high carbohydrate diet show improvement. The reduction of sugar level occurs gradually and unlike insulin does not cause hypoglycaemia.

SURGERY

Very little original work in the field of surgery seems to have been done in India during the nineteenth century and the beginning of the twentieth. An outstanding contribution to surgery was, however, the invention of forceps known as 'Bengal forceps' (a modification of Simpson's) by K. N. Das (1912) so as to adapt it for use on Bengali women. Forceps with 7/8th measurements

of the pelvis and suitable for full-term baby weighing 6/7ths of the weight of a British baby were found to cause injuries to the mother in Bengal. There were two types of 'Bengal forceps', the ordinary and axis-traction types. The ordinary type is about 10 oz. less in weight than the foreign ones. The pelvic curves are a little more pronounced and the distance between the shanks near the joint is wide enough to admit the forefingers. The handles are made like amputation knives and give an efficient hold without adding much to the weight of the instrument. Moreover, being flat, they allow the thumb to rest as a fulcrum very effectively during the final stage of extraction of the head of the baby. The shoulders which are made as small as possible merge gently into the handle so as to allow the operator's fingers to rest comfortably.

In the axis-traction variety, blades are fitted with axis-traction rods which are supplied with Down Bros' registered catch. The hollow traction handle is about 3" long and is made as light as possible. At the lower end of the handle of the left blade there is an adjusting screw with a butterfly nut which is received into a grooved ring attached to the lower end of the handle of the right blade.

PROGRESS AFTER INDEPENDENCE

Medical research was intensified after independence. In the field of indigenous drug research, Dutt and Ghosh (1947) confirmed the findings of Gupta and his co-workers (1946) that *Deamia extensa* (syn. *Pergularia extensa*) was a smooth muscle stimulant. Ojha and his associates (1949) showed that the extract of wood *Pterocarpus marsupium rox* (*bandhuka puṣpa*) was effective in lowering blood sugar in diabetes when given orally and that it did not produce any toxic symptom. Bhattacharji and associates (1952) as also Dutta and co-workers (1952) showed that *Cessampelos pariera linn* was likely to be useful in leucoderma.

Pal (1947) showed that sulpha drugs in heavy doses had a toxic effect upon the heart with symptoms of irregularity, grouped beats, extreme slowing, and sometimes complete stoppage which could be prevented by a simultaneous administration of sodium bicarbonate or sodium acetate. The action of the drugs is mainly on the cardiac muscle and to some extent on the ganglia (stimulation). In bigger doses there is a fall of blood pressure, too. In 1950 Pal and his co-worker used radio-iodine (I^{131}) for the first time in India for the successful treatment of Graves' disease. Mukherjee (1948-57), working on chemotherapy for cancer, found a good response with a complex phosphotungstic molybdic acid (PTMS). De and Sengupta (1951) experimentally shunted blood from the cortex to the medulla of the kidney to produce a haemodynamic change, which indicated that nephrosis was likely the cause in experimental allergy. Rindani (1953) observed that adreno-cortical

activation by stress was prevented by pretreatment with reserpine-free extract of *Rauwolfia serpentina* (anti-stress agent), although the drug did not modify the action of either ACTH or cortisone. He also demonstrated a peripheral antagonism between gluco-corticoids and mineralo-corticoids in inflammatory conditions.

Das Gupta and co-workers (1954) observed that out of the fourteen amino-acids, l-leucine and l-valine were found to undergo oxidative de-amination in both heart and lung tissues. Venkatachalam (1954) described a full-fledged 'Kwashiorker' syndrome in India thus: 'The child with the fully developed disease is one which has been on a low protein diet for some time, shows evidence of failure of growth, suffers from extreme lassitude, peevishness and anorexia, exhibits oedema and may have characteristic skin, hair changes and fatty liver.' In such a condition, Gopalan and Ramalingaswami (1955) obtained good results from the use of skimmed milk and also comparable results from the use of pulse proteins.

Banerjee (1956) confirmed the insulin-sparing action of vitamin C, reported earlier by him in 1952. With 25 mg. of vitamin C, the insulin dose could be reduced to half, but carbohydrate in the diet could not be increased unless 100 mg. of this vitamin was given.

Anand and Dua (1956) reported definite rise in blood pressure on stimulation of the temporal tip of the limbic area, and inhibition of the mobility of stomach on stimulation of the temporal lobe structures. Sen and Anand (1957) showed that stimulation of the preoptic region of the hypothalamus and the anteromedial group of amygdaloid nuclei produced acute haemorrhagic ulcer in the gastric pouch. On the other hand, Anand and his associates (1959) demonstrated that lesions produced in the limbic structures of the frontal lobe resulted in a slight drop of blood pressure with a rise in the heart rate.

Chatterjee and co-workers (1956) gave an account of electrophoretic analysis of haemoglobin in Cooley's anaemia and produced evidence of interaction of *thalassaemia gene* with that of abnormal haemoglobin. Later on (1957), they gave an account of E-thalassaemia disease with a high incidence in West Bengal (nineteen cases in a series of thirty-one families).

Sanyal and Guha Sarkar (1957) discussed fully the utility of various tests for oral contraceptives, m-xylohydroquinone and its substitutes, 3 : 5 and 2 : 6 dimethylpheno-oxyacetic acid. According to Sanyal (1957), the second one, applied in the oestrogenic phase of the menstrual cycle, is capable of contraception by enhancing the peripheral oestrogenic effect on the uterus and thereby counteracting the progesterone effect, while the first one would do the same by diminishing the effect of oestrogen and necessarily minimizing the progesterone effect, thus preventing deciduomatous formation and causing

temporary sterility. Mukherjee (1957) proved that in human malignant disease chemotherapy was possible with a complex phosphotungstic molybdic acid. By centrifuging the seminal fluid of an ox, Bhattacharya (1958) in Germany successfully separated the heavy spermatozoa for artificial insemination of cows, which resulted only in male offspring. He claimed this principle to be applicable to human beings as well, for having a male or female issue at will.

Pal and co-workers (1965) prepared two new oral hypoglycaemic drugs—(1) N′-P sulphonamidophenyl guanyl urea hydrochloride (S.G.U.) and (2) N′-P sulphonamidophenyl biguanide hydrochloride (S.B.G.)—and tried them on experimentally induced diabetic dogs and cases of human diabetis mellitus. Of the two drugs the first proved to be a better one—as effective as, if not better in some respects than, other sulphonyl urea drugs like Rastinon and Nadison. In the early sixties Roy, Pal Choudhury, and others did valuable researches under Professor Pal in the department of physiology of the R. G. Kar Medical College, Calcutta, on stress syndrome due to burns, fractures, bacterial poisons, and different types of anaesthesia. H. G. Khorana, an Indian naturalized in the U.S.A., was awarded the Nobel prize for medicine in 1968 for his outstanding researches on DNA.

As regards progress in surgery, by far the most outstanding work was that of Mitra (1955) for extraperitoneal lymphadenectomy with radical vaginal operation for cancer of the cervix, overcoming the disadvantage of recrudescence and death within five years for not removing the regional glands by the classical routine operation. In this connection Purandare's surgical technique is also worth mentioning.

In case of failure of conservative treatment, Menon (1955) advocated early caesarian section in severe antepartum eclampsia where the cervix was closed and the presenting part was unengaged, which definitely reduced mortality. But when the patients were in labour or when the cervix was ripe and the presenting part was engaged, artificial rupture of the membrane was still the treatment of choice.

Misra (1954) recommended one-stage right hemocolectomy where the lesion was mainly above the ileocaecal valve. For lesions higher up in the ileum, up to 20 inches of the ileum could be included in the resection and where multiple strictures were present anastomoses were preferred for extensive resection. In all cases adequate blood transfusion and suitable chemotherapy were also to be insisted on.

Mahadevan Pillai and Rama Murthi (1955) advocated a special method for carotid angiography for the diagnosis of tumour, cysts, abscess, aneurism, tuberculosis, subdural haematomata, and metastasis of malignant tumours of the brain as well as pituitary tumours. According to this method, the physician, after making sure that the needle has been introduced percutaneously into the

carotid artery, injects a suitable dye whereupon skiagrams are taken. Sen and Das Gupta (1956) advocated vagotomy with gastro-jejunostomy in the case of chronic duodenal ulcer in feebled and undernourished patients unfit for gastrectomy. The result was satisfactory in 94 per cent cases with no mortality. Choudhury and his associates (1956) reported good results after splenectomy in cases of 'Tropical Bengal splenomegaly'.

In 1975 S. Mukherjee was successful in growing in a sterile woman a test tube baby, the first of its kind in India. His method consisted of the following stages: (i) a fully developed ovum was extracted by operation at the time of its emergence into the fallopian tube and put in a nutrient medium in a test tube, which was deposited in a refrigerator; (ii) the ovum was impregnated with sperm cells obtained from the husband; (iii) fertilization and growth of the ovum continued in the frozen atmosphere for a period of two to three days; and (iv) the fertilized ovum was implanted inside the uterine cavity and pregnancy was allowed to proceed to full term.

Encouraged by successful heart transplantation operations in South Africa by Bernard and at Houston, U.S.A., P. K. Sen tried the same on a patient in Bombay, unfortunately, with no success. Recently, R. Mendez and his assistant S. Chatterjee have successfully done kidney transplant operations, using monoclonal antibody, at St. Vincent Medical Centre in Los Angeles, U.S.A.

The foregoing survey brings the account of the development of western allopathic medical sciences in India up to around 1982. Since then there has been some progress in various areas of the study, practice, and research in western medical sciences in this country.

Mention may be made in this context of the Indian Council of Medical Research (ICMR), New Delhi. Set up in 1911, it has now a network of research institutes and centres covering a wide spectrum. Among them are fifteen permanent research institutions and centres, namely National Institute of Nutrition, Hyderabad; National Institute of Virology, Pune; Tuberculosis Research Centre, Madras; National Institute of Cholera and Enteric Diseases, Calcutta; Institute of Pathology, New Delhi; National Institute of Occupational Health, Ahmedabad; Institute for Research in Reproduction, Bombay; Central JALMA (Japanese Leprosy Mission for Asia); Institute for Leprosy, Agra; Blood Group Reference Centre, Bombay; Vector Control Research Centre, Pondicherry; Malaria Research Centre, Delhi; Institute of Research in Medical Statistics, New Delhi; Food and Drugs Toxicology Centre, Hyderabad; and Cytology Research Centre, New Delhi. All these bodies are engaged in the most up-to-date studies and research in medical and allied sciences in their relevant spheres. Besides these, there are two statutory bodies, the All India Institute of Medical Sciences, New Delhi, and the Post-Graduate

Institute of Medical Education and Research, Chandigarh, which conduct research in various branches of medical science. Selected research projects in relation to kala-azar, plague, and other infectious diseases also get financial assistance from the Directorate General of Health Services of the Government of India.

Specialized Study of Diseases and Treatment: Among the institutions doing specialized work in a particular branch of medicine or in the treatment of specific diseases are: Indian Cancer Research Centre, Bombay; Cancer Institute, Madras; Chittaranjan Cancer Research Centre, Calcutta; National Tuberculosis Institute, Bangalore; and Vallabhbhai Patel Chest Institute, Delhi, where research in chest ailments including tuberculosis is done. The Central Leprosy Teaching and Research Institute, Chingleput, where medical and paramedical personnel are trained and leprosy patients are treated, has been recognized as a WHO regional centre for certain investigations in leprosy. The National Institute of Communicable Diseases, Delhi (previously known as the Malaria Institute of India established in 1909), with its seven branches throughout the country is engaged in research, training, and rendering service to victims of communicable diseases. It also plans, guides, and evaluates the national filaria control programme which has been designated as a WHO reference. The All India Institute of Hygiene and Public Health, Calcutta, set up in 1932, undertakes training and research in the fields of public health, family planning, nutrition, and allied matters. Biological and chemical appraisal of drugs is carried out at the Central Drugs Laboratory, Calcutta.

Microbiology and Related Studies: The Central Research Institute, Kasauli, is the drug laboratory for all biological products. The Institute functions as the national centre for giving expert advice to both the government and public on rabies, yellow fever, snake-bite, cholera, typhoid, whooping cough, tetanus, and diphtheria. It carries out both basic and applied research for the prevention of these diseases. It has started preliminary work for the production of measles vaccine and has also prepared a project report for the production of Japanese encephalitis vaccines. The Pasteur Institute, Coonoor, also does research in rabies, influenza, respiratory virus infections, diseases caused by intestinal viruses like polio, Coxsackie and ECHO group and bacterial diseases like enteric fevers and syphilis. It is the main centre for research on rabies and influenza in the country as also the international reference centre of WHO on rabies and national centre for work on influenza. The King Institute of Preventive Medicine, Guindy, Madras, gives post-graduate training in microbiology, supplies prophylactic vaccines, freeze-dried small-pox vaccine, anti-tetanus sera, tetanus toxoid, blood products and intravenous and special solutions of various kinds. The Haffkine Institute, Bombay, established in

1896, does research in bacteriology, experimental medicine, chemotherapy, pharmacology, pathophysiology, biochemistry, immuno-haematology, immunology, and virology related to communicable and other diseases.

II

INDIGENOUS SYSTEMS AND HOMOEOPATHY

Simultaneously with the progress in western allopathic medical sciences, the indigenous systems of medicine still hold their ground and are particularly popular in the rural areas. According to official estimates, 278,000 registered medicos practise these systems through 13,535 dispensaries and 371 hospitals with 11,118 beds. There are ninety-five Āyurvedic, sixteen Unani, and one Siddha undergraduate colleges in the country. The Central Council of Indian Medicine regulates the practice of, and education in, Āyurveda, Unani, and Siddha systems.

Homoeopathy: Homoeopathy is quite popular in India not only in villages but in urban areas also. There are eighty-three hospitals with 2,249 beds, 1,806 dispensaries, and 109,000 practitioners for homoeopathy in the country. There are 122 institutions recognized by various State boards and councils imparting training in homoeopathy. The Homoeopathic Advisory Committee advises the Central Government on the development of homoeopathy. Under the Homoeopathic Central Council Act, 1973, a Central Council of Homoeopathy was set up in 1974. It determines the minimum standards of homoeopathic education throughout India and maintains a central register of homoeopathic practitioners.

Higher Studies and Research: For research in Indian medicine and homoeopathy there are four constituted bodies: (i) The Central Council for Research in Ayurveda and Siddha, (ii) The Central Council for Research in Unani Medicine, (iii) The Central Council for Research in Homoeopathy, and (iv) The Central Council for Research in Yoga and Nature Cure. The Central Council for Research in Ayurveda and Siddha undertakes research programmes through twenty-five research institutes and sixty-seven research units. The programmes comprise clinical studies of different diseases including malaria and allergic disorders; inter-disciplinary studies on drugs; pharmacognosic work on drugs; and medico-botanical survey of forest areas. The Central Council for Research in Unani Medicine runs among other organizations one central and three regional research institutes. Clinical research is conducted on different diseases like vitiligo, leucorrhoea, sinusitis, jaundice, malaria, and trachoma. Similarly, the Central Council for Research in Homoeopathy has under it one central research institute, two regional research institutes, and

twenty-five research units to conduct clinical and drug research. Useful results have been obtained by the Council in the treatment of bronchial asthma, allergic dermatitis, amoebiasis, tonsillitis, sinusitis, rhinitis, and arthritis. Six lesser known drugs in homoeopathy have been proved under the drug proving programme and over thirty drugs have already been standardized. The Central Council for Research in Yoga and Nature Cure runs four leading yoga research institutes which are conducting research on diseases like diabetes mellitus, bronchial asthma, hypertension, arthritis, and chronic gastrointestinal disorders. Intensive work is being carried out in the central yoga research institute in collaboration with the All India Institute of Medical Sciences to study the effects of yoga on various metabolic activities in the body[1].

[1]*India 1982* (Publications Division, Ministry of Information and Broadcasting, Government of India), pp. 101-102.

24

GEOLOGY AND MINING

EARLY records of the East India Company since the Battle of Plassey in 1757 do not show any discovery of rich mines though they contain detailed information on the jewellery and silverware held by the Indian princes. Between 1763 and 1782 Major James Rennel carried out valuable topographical surveys leading to discoveries of coal and iron ore. In 1777 Heatley and Summer discovered coal near Sitarampur in West Bengal. The mines started production in the same year when Motle and Farquhar applied to Warren Hastings for permission to erect an iron works in the vicinity. With the fall of Tippu Sultan (1799), the Marquis of Wellesley deputed Francis Buchanan (Hamilton) to explore Mysore and Malabar. Buchanan came across a local reddish brown building-stone which was soft when freshly quarried but hardened on exposure. He named it 'laterite'. Henry Westley Voysey, a surgeon and geologist, accompanied Buchanan in his survey northwards into Hyderabad. This perhaps marked the first official appointment of a geologist in India.

Peninsular India: Voysey may be called the father of Indian geology. His excellent contribution, *The Diamond Mines of South India,* was published in 1833. It describes in detail the mode of occurrence of diamond and its mining operations. P. M. Benza (1835), surgeon to the Governor of Madras, contributed a paper on the geology of the Nilgiris which described in detail the mineralogy of the granitoid rocks, the basalt dykes, and different types of iron ores found in the Nilgiri Hills. T. G. Malcalmson (1835-36) of the Madras Medical Service was another early investigator of the geology of India. Besides discovering in 1832 the vast spread of plateau basalts known as the Deccan Traps, he identified the intertrappean limestones in the Nirmal Hills of Godavari district. He was the first to record and describe the Lonar Lake in the Buldana district of Maharashtra as a vast crater nearly 500 feet deep and four to five miles along its outer periphery. J. Homfrey's (1842) description of the Damuda valley was the first published account of the Raniganj coal-fields. W. S. Sherwill (1845-54) of the Revenue Survey contributed articles on the geology of Shahabad and Bihar including a fine description of the geology of the Rajmahal Hills. His conclusions on the origin and other aspects of the rock-formation were so sound and logical that these underwent little change in the years that followed. He had also discussed the coal occurrence of the Chuparbhita Pass.

Thomas Oldham (1854-76) examined in detail the Rajmahal Hills and the coal measures in Bengal including the Damuda, Ajay, Ramgarh, and Karhar-

bari coal-fields. He concluded that the entire coal formations of Bengal were quite different and distinct from those of England. He gave the name Vindhyan to the great sandstone formation of northern and central India.

Haughton (1854), who examined the geology of Singhbhum, was the first to detect the two major rock divisions in the metamorphics, namely, the gneisses grading at places laterally into granites and the schists and slates. P. M. Keating (1856-58) was the first to study and report on the cretaceous formations of Trichinopoly (Tiruchchirapalli) and Pondicherry. W. T. Blanford (1860) classified the Raniganj beds, while Godwin-Austen (1869) of the Topographic Survey described the physiography and geology of the Khasi-Jaintia Hills in Assam. Godwin-Austen found the metamorphics, the oldest rocks, overlain by sandstones and shales with associated coal seams. Ball (1881) was the first to give an account of the geology and mineral resources of the Andaman-Nicobar Islands. His description covers the Nicobar, Ross, and Viper Islands, the coastline at Port Blair, Mont. Haneh, etc. and he lists the coal, serpentine, and iron occurrences.

The earliest reference to European enterprise in geological exploration was in connection with coal when in 1774 trained miners from Europe were brought to mine coal near Sitarampur. The subsequent discoveries of coal by non-geologists together with the high cost of imported coal led to a strong recommendation by the coal committee for a thorough investigation of the coal-fields, and D. H. Williams of the British Geological Survey was deputed to survey the coal occurrences. The foundation of the Asiatic Society in 1784 covering a wide field of geology, including palaeontology and palaeobotany, as well as the establishment of the Indian Museum in 1796 gave further impetus to scientific work in India. The year 1840 marks the beginning of modern geological work when the geology and palaeontology collections kept in the museum of Asiatic Society were housed in a separate museum of economic geology by the Government with H. Piddington as its first curator. Piddington measured the quantity of silt in the Hooghly for each month of 1842.

Himalayas: J. D. Herbert (1815-30) carried out a survey of the mineral occurrences of the Himalayan districts and was the first to officially attempt compilation of a geological map of a considerable part of the Himalayas. He also tried a comparative study of the Himalayan fossiliferous strata and European formations, the first such venture in India.

H. Falconer (1831) carried out a geological exploration of the Siwalik Hills, confirmed their Tertiary age, and placed them along with Molasse formations of Switzerland. He published a good account of the geology and physiography of the Siwalik ranges and illustrated the relationship of the Siwaliks to the main Himalayas by suitable sketches and cross-sections. R. Everest (1833-35), who journeyed from Mussoorie to Gangotri, has mentioned

the following successions in an ascending order: (1) granite, (2) gneisses and mica schists, (3) talcose gneisses and talc schists, (4) clay-slate, (5) Mussoorie limestones, and (6) quartz rocks.

Between 1839 and 1847 T. Hutton explored the Spiti valley and this work was followed up in 1850 by W. C. Hays. H. B. Medlicott of the Geological Survey of India established that the so-called saliferous sandstone of Kumaun corresponds at least in part to the Nahan sandstone, and also confirmed the great stratigraphic and physical break between the Nahans and the Siwaliks of the outer hills.

H. Godwin-Austen (1865) explored the Bhutan Duar and reported lignite in sandstones overlain unconformably by horizontally-bedded conglomerates. His records did not mention coal. He, however, discovered in the bed of the Diama river, a short distance west of Buxar, fossil molar teeth of an elephant, probably washed out of the conglomerates. A. M. Verchere of the Bengal Medical Service contributed a voluminous paper on the geology of Kashmir, the western Himalayas, and the Afghan mountains. According to him, prior to the Carboniferous and during the Silurian period there existed in the centre of Asia a sea connecting the Arctic to the Indian Ocean with a chain of volcanoes aligned NE-SW, where the present Afghan mountains stand. In this paper he traced the geological history of the area from the Mesozoic through the Tertiary to recent times. A. Fleming (1848-53), the first to study the Salt Range in detail, was joined by W. Theobald in 1854, and together they carried out detailed geological, mineralogical, and palaeontological studies.

Several other foreigners explored the interior regions of the Himalayas and reported on the glaciers and the rivers that flow through the mountain terrains. For instance, J. A. Hodgson visited the source of the Ganges in 1817 and published his discoveries and observations on the glaciers in the fourteenth volume of *Researches and Journal of Asiatic Society*. Baton and Manson (1842) described the glaciers of Kumaun at Milm and Anta Dua Pass and Weller described the glacier at Bulaba Pass. E. Madden of the Bengal Artillery made an excursion to the Pinder glacier in September 1846. R. Strachey (1848) was the first to make a systematic study of the Himalayan glaciers. He made accurate measurements of the rate of movement of lateral and medium moraines in them. Godwin-Austen, describing in an article the Pangong Lake limestone of Ladakh, pointed out numerous evidences of ice action in the Kashmir territory. He detected a glacial period even as low as the valley of Jhelum at Baramula. W. T. Blanford (1871) in his account of eastern and northern Sikkim described the traces of former glaciers which he had observed in Tista valley at elevations of 5,000 to 6,000 feet. J. F. Campbell (1877), author of *Frost and Fire*, recorded total absence of glacial action between the Ganges and Ravi rivers in the Mussoorie Hills and the country north-west of Simla. He

noted, however, the presence of great blocks of gneiss along Dhuladhar in the Kangra valley, the only direct evidence of the preserved glaciation. But H. B. Medlicott, who also visited the Kangra valley, explained the great boulders as due to normal alluvial action. R. Everest (1832) instituted a series of experiments to determine the earthy matter brought down by the Ganges at Ghazipur.

Geological Survey of India: The Geological Survey of India owes much for its establishment to J. McClelland who, as Junior Member and Secretary of the Committee for the 'Investigation of the Coal and Mineral Resources of India', had collected since 1837 useful information regarding the distribution of coal-bearing formations in eastern India. It was due to him that D. H. Williams was called out in 1845 from the British Geological Survey 'for the purpose of making a geological survey of those districts in which coal-fields are situated'. The work of Williams on the investigation of the coal-fields of India led to the establishment in 1851 of the Geological Survey of India with Thomas Oldham as its first Superintendent. Oldham put the Survey on a sound footing. He initiated the study of earthquakes after the Cachar earthquake of 1869 and prepared the first catalogue of events. It was decided in 1856 to start east-to-west geological surveys of the coal-fields. During the period 1858-60, Blanford made a thorough and systematic survey of the coal-fields of Raniganj, preparing a geological map of the same and proposing the names for Lower Gondwanas (Talchir, Damuda, and Panchet), which were retained by subsequent workers. The other coal-fields were surveyed by pioneers like C. S. Fox, Mallet, and V. Ball. It was Medlicott who first proposed the term 'Gondwana System' for the major coal measures of India after the ancient Gond kingdom in Madhya Pradesh, and also brought to light the geological structure of the Himalayas. Similarly, in his surveys north of the Narmada valley (1854-59) he established the 'Vindhyan System' and suggested a threefold classification. Medlicott took charge as Superintendent of the Geological Survey of India in 1876 and continued his extensive survey of extra-peninsular India assisted by R. Lydekker, Theobald, C. L. Griesbach, and others. The structure of Kashmir and the Punjab Himalayas was studied. In 1877 Lydekker, after working in the mountainous tracts of the Kashmir valley and the upper Chenab and Hundes basins, observed that the Kashmir valley was a compressed synclinal ellipse and gneisses of the Kailash range were locally Silurian. Griesbach concluded that the two ranges Zanskar and Pir Panjal were the offshoots of the main Himalayan range. Further researches led to the conception of the growth of the Himalayas in stages from the Sea of Tethys. The study of Himalayan glaciers was initiated by Hayden with the help of fossilized mammalian remains. Mallet, F. Stoliczka, and Theobold made expeditions to the Sutlej and Spiti valleys and the higher

Himalayas to collect Mesozoic and Palaeozoic fossils. Wynee was the first palaeontologist in India who worked on the Salt Range and the Jurassics of Kutch, making a rich collection of fossils.

The geological survey of South India was started by Blanford in 1857 in the Nilgiris. The marine cretaceous formations of Trichinopoly and South Arcot districts were studied. W. King took over in 1887 as Director of the Geological Survey and concentrated on the economic deposits of India. The coal-fields of Hyderabad, Chattisgarh, and Bihar as well as the gold, mica, and steatite deposits of Mysore and Bihar were studied. The Survey assumed the responsibility of imparting geological education when T. H. Holland was deputed as part-time professor of geology in the Presidency College, Calcutta.

Oil shows of the extra-peninsula were studied by Pascoe who was an authority on petroleum. Mining specialists were appointed by the Geological Survey when Griesbach took charge as its Director in 1894. In 1902 the Division of Mineral Investigation was started. The specialists concentrated on the Kolar and Wyanad gold-fields, and the coal-fields of Rampur, Talchir, and south Rewa. Petrological studies were added by P. N. Bose. The Survey's attention was drawn to civil engineering problems after the Bihar-Ganges valley landslide and Holland was later sent to investigate the suitability of the dam site.

Holland, who succeeded Griesbach as Director in 1903, had been in the Survey since 1890. He is remembered for his unique discovery of Charnockite (pyroxene-bearing rock) in 1893 and for publishing a classical memoir on the subject in 1900. He was the first to recognize the identity of bauxite and laterite. He was instrumental in laying the foundation of the Geological Society of India and the Mining and Geological Institute (now Mining, Metallurgical and Geological Institute of India). Systematic mineral and geological surveys continued to receive greater attention at the hands of successive Directors like H. H. Hayden (1910-21), E. Pascoe (1921-32), and L. L. Fermor (1932-35). The detailed survey of Gondwana coal-fields by Fox, the attempt by E. R. Gee to solve the age of the Himalayan Saline Series, the classic work on manganese deposits by Fermor, and Pilgrim's contributions on the Siwalik fossils deserve mention. Pilgrim worked on the Siwaliks and discovered a rich heritage of mammalian fauna. His study of drainage during mid-Tertiary times in North India brought about the concept of the 'Siwalik or Indobrahm river'.

Fermor was the first to introduce the study of polished sections of ores in reflected light and the use of needle for prospecting iron and manganese ores. Heron, who succeeded Fermor as Director in 1935, had studied the Aravalli System in Rajasthan. Other important contributions of this period comprised Wadia's classic work on the structure of Kashmir Himalayas,

West's work on Simla windows, Crookshank's account of the Cuddapahs, and Krishnan's study of the Gangpur series. With the advent of World War II, the Survey concentrated on the development of strategic minerals. In the succeeding years with the setting up of circle offices and separate sections for groundwater, engineering geology, and geophysics, the Survey's work continued to expand rapidly. The information obtained by the department in the course of its survey work was made available to the public through published accounts accompanied by maps.

Teaching of Geology: Oldham was a pioneer in teaching geology to Indians. His first three Indian students were Ram Singh, Kishen Singh, and Hiralal. A part-time post of teacher in geology was created at the Presidency College, Calcutta, in 1892. Holland, as already mentioned, was deputed from the Survey to this post. He organized the geology department of the college where Hayden, P. N. Dutta, C. S. Middlemiss, and Walker also served as lecturers. Post-graduate studies in geology were provided in 1916 at Calcutta University. The Presidency College, Madras, had introduced the teaching of geology in 1886. In 1889 the Central College, Bangalore, opened a geology section which was expanded after the formation of Mysore University. In western India Ferguson College, Poona, started teaching geology in 1908. During the early part of this century different institutions in northern and eastern India introduced this subject. These include St Xavier's College, Bombay (1918), Banaras Hindu University (1920), and Indian School of Mines, Dhanbad (1926). With the growing demand for geologists, this trend continued as many more institutions in different parts of the country started teaching the subject during the forties. Chief among them are the Universities of Andhra (1941), Lucknow (1943), Aligarh (1945), Patna (1945), Saugar (1946), Jabalpur (1947), and Gauhati (1950). At present almost every university has got its own geology department. Besides, the number of colleges teaching geology has also increased.

PROGRESS OF VARIOUS BRANCHES OF GEOLOGY

The following is an account of the progress made in India in different branches of geology.

Stratigraphy: The geology of the more important Pre-Cambrian terrains has been worked out in greater detail in Mysore, Rajasthan, Madhya Pradesh, Gangpur, Singhbhum, Manbhum, and the Eastern Ghats region. More recently, radioactive age determinations have been made to build up a connected geochronology. A few mineral ages, determined mostly outside India, are now available and considerable importance is being attached to these data for correlation of the Pre-Cambrian formations. The Palaeozoic strati-

graphy of the Salt Range, Kashmir, the Umaria marine beds of Madhya Pradesh, and the Permo-Carboniferous horizons in the eastern Himalayas has received the greatest attention. The structural features of the Himalayas like nappes and overthrusts, klippen and windows have been studied in detail. In the stratigraphy of Deccan Trap formations the age of the inter-trappean beds has been of great interest.

The sequence of Palaeo-Mesozoic freshwater deposits making up the Gondwana System of Peninsular India has been widely studied, classified, and correlated. Revised knowledge of the palaeography and distribution of some Gondwana plants and discovery of new stratigraphic breaks and relations in the field led to new schemes for classifying the Gondwana sediments.

Palaeontology and Palaeobotany: Palaeontological studies in India have been coupled with stratigraphic-palaeontologic enquiries and have led to some monographic works. Of late, emphasis has been laid on micropalaeontology as an aid to oil and coal exploration.

The earliest mention of fossils in India was by the historian Feriston. John Warren reported in 1810 the occurrence of 'Petrifactions in Treevikera village, Carnatic'. The first Himalayan vertebrate fossils were discussed by W. S. Webb in 1824. The first palaeolith was discovered by Bruce Foote in 1863 at Pallavaram near Madras. This suggested that India, one of the cradles of civilization, might well be the soil where the human race had sprung up or at least that its antiquity here went much farther back than some had been inclined to concede. Gerhard's account of these discoveries from Spiti is the earliest detailed illustrated paper on Himalayan fossils. Salter, Blanford, Stoliczka, Davidson, and de Verneil contributed much on the Palaeozoic and Mesozoic fossils of the central Himalayas, Spiti, and Kashmir. The work of leading palaeontologists like Sowerby, Carter, D'Archaich, Waagen, Kitchin, Cox, and Spath on ammonites and cephalopods of foraminifera richly deserve mention.

Invertebrate fauna, in most cases composed of varied elements, was treated in comprehensive works with emphasis often on the dominant elements. Thus trilobites, foraminifera, brachiopods, lamellibrachs, and cephalopods received greater attention; echinoids, corals, bryozoans, and algae have been collaterally studied.

The study of foraminifera and ostracods received a greater impetus recently, thanks to India's efforts in oil exploration. Earlier works in general were more comprehensive, while later works were usually of limited interest.

Among vertebrates, studies on primates have been few. The rather rich development of highly differentiated anthropoids (*Sivapithecus*, *Dryopithecus*, *Palaeopithecus*) may perhaps be taken as an indication of the ushering in of the human successions. The rich proboscidean fauna of the Siwaliks of Sind

(now in Pakistan), Kashmir, Burma, and the Narmada and Godavari valleys received early appreciation.

From the point of richness of fossil fauna, the Salt Range stands unrivalled in comparison with any other part of India. W. S. Webb was the first European to record vertebrate fossils. Although the grand procession of Indian vertebrates commences practically with the Permo-Trias, it is the Siwalik forms that lead in a magnificent array. A number of important contributions on Siwalik mammals have been published by Falconer, Lydekker, Coutley, Bruce Foote, Colbert Osborne, and others. The evolution and migration of animals were also studied. The dinosaurian remains of Madhya Pradesh showed close affinities with those discovered in Madagascar, Patagonia, and Brazil, indicating the existence of land bridges between India and other countries across the Indian and Atlantic Oceans, that is, the persistence of remnants of the old Gondwana Continent in cretaceous times.

Palaeobotanic research in India started with the discovery of lower Gondwana fossils like *Glossopteris* by Adolf Bragnant. Classic studies on the fossil flora of Gondwana by Feistmantel, Oldham, and Morris late in the nineteenth century were followed by the rejuvenation of palaeobotany by others. Further work on fossil plants was done by geologists like Carter, Grant, Hislop, and Hunter. The list of Gondwana flora as well as other Indian plant fossils underwent revision by Seward, Sahni, and others. Since then further revision of a more fundamental nature has been made especially in applied micropalaeontology, fossil-algae, and Tertiary and Pleistocene floras. Pteridophytes form the bulk of Indian palaeobotany in specimens. The rich *Glossopteris* flora of India were studied in detail and compared with those of China, Europe, and other areas. Microspore studies were carried out with a view to ascertaining the validity of strata zones with spores and of seam identification. Pollen analysis of successive horizons of the lower Karewas of Kashmir showed the onset of the first interglacial period. There was probably more aquatic vegetation dominated by Trapa. The biostratigraphic significance of a few genera of microspores from collieries like Jhagrakhand was realized. In the present century Birbal Sahni made fundamental contributions to the science of palaeobotany and established an institute of palaeobotany at Lucknow for further advancement of the study of the subject.

Petrology: The Geological Survey of India was primarily engaged in systematic mapping. But the attention of geologists was now and then drawn to problems of purely petrological interest. This led to the classic works on Charnockites, the Deccan Trap basalts, the alkaline rocks of Coimbatore, the Kodurite and Khondalite series of rocks, and laterite and bauxite, among other things. After independence petrological research was undertaken on a variety of rocks like the granites of Chotanagpur, Singhbhum, and Dhalbhum,

the granophyres and soda granites of the thrust zone in Seraikela, the Bundelkhand gneisses, the Erinpura granites, the Himalayan granites, and the Archaeans of Mysore including the Clospet and Chamundi granites. Much emphasis has been laid on igneous, sedimentary, and metamorphic rocks. Volcanic rocks like the Deccan basalts and submarine pillow lavas of Mysore have been studied in detail.

Metamorphic studies dealt particularly with the spatial distribution of metamorphism and its relation to structure, stratigraphy, and mineralization. Metamorphic rocks of the eastern Himalayas, Rajasthan, Madyha Pradesh, Gangpur, Singhbhum, and other areas were studied extensively. Sedimentary formations of the Cuddapahs and Vindhyans were thoroughly investigated and correlated. Sedimentary petrology emerged as a separate discipline in the early part of this century.

Mineralogy: Minerals have been studied as distinct entities secondarily in connection with either a new find or petrographic investigations or out of the necessity for knowing the mineralogy and genesis of economic ores like iron, manganese, chromite, mica, gold, and copper. Much headway was made in the field of pyroxene and feldspars in India. Apart from optical studies, the discovery and identification of new minerals have also been attempted. Mention may be made of the discovery of manganese minerals like sitaparite and vredenburgite. Even physicists like the Nobel laureate Raman have made excellent contributions on optical anisotropy and heterogeny of vitreous silica and iridiscence phenomena in quartz crystals. A series of studies on the chemistry and petrology of coals, their sulphur content, and their reflectance characters have been carried out. Further exploration works led to the discovery of a number of new Indian oil-fields in the present century. Apart from Assam, new areas in Bombay, Gujarat, Rajasthan, and the Punjab have been placed on the oil map.

Economic Ores: As stated earlier, due to the pioneering work of the Geological Survey of India, a number of sites bearing Fe, Mn, Cr, Au, and Ag deposits have been discovered. Similarly, sites with deposits of mica, asbestos, talc, fluorite, etc. as well as marble and sandstones have been located.

Geodesy: Geodetic researches in India pertaining to isostasy and shape of the Geoid have been carried out mostly by the Geodetic Branch of the Survey of India. The precise detection of a discrepancy of 5″ arc in the Himalayan region during the Great Triangular Survey of India led to the proposition of the classical Bract-Hayford and Airy-Heiskanan concept of isostasy.

Groundwater Development: The earliest bore-holes on record were probably those drilled in the Gangetic alluvium for obtaining artesian supplies of water. The first was perhaps bored in 1804 at Calcutta, and was followed by twenty-three others including the bore-hole of 481 depth at Fort William in 1838.

A 700′ bore-hole was sunk at Ambala in 1872 and a 1,612′ hole in 1925-27. Geological interpretation of bore-hole data and their bearing on the hydrological conditions of Gangetic alluvium appear in Geological Survey of India publications from 1881. In 1909 Pickering described an apparatus of his own device consisting of a float and a counterpoise for making accurate flow measurements of water pumped from a well in the Palana coal-field. Mallet reported in 1870 on the water supply of Aden which was under the administrative control of India. The first large scheme in which engineers, hydrologists, and geologists worked in close collaboration in preparing the blueprints was the Ganges Valley State Tube-well Irrigation Scheme (1936) The alluvial tracts of Gujarat and arid tracts of Jodhpur, Bikaner, Ajmer-Merwara, Madhya Pradesh, Delhi, Punjab, Uttar Pradesh, Madras, and other areas have been surveyed.

Engineering Geology: The first engineering geology investigation was done by T. Oldham in 1854 in connection with the proposed extension of railway line to the Raniganj coal-field. The geological and geographical factors responsible for the disastrous landslip which dammed the valley of the Ganges were examined by T. H. Holland in 1894. R. D. Oldham and Holland examined in 1895 and 1896 respectively the stability of the Government House building in Naini Tal and suggested measures to safeguard it. Holland examined dam sites for the first time in Madras and Mysore in 1898-99. The Ganges canal in Uttar Pradesh (1854) and the Godavari and Krishna delta systems in Andhra Pradesh (1855) stand as monumental works in the field of engineering geology. So are the Kharakvasala dam, the Jhelum-Chenab and Ravi projects, Sutlej project, Sukkur barrage (1932), Mettur, Tungabhadra and Lower Bhawani, Hirakud, Tilaya, Konar, and Maithon dams.

Earthquakes: The scientific study of earthquakes in India began with the publication in 1883 of T. Oldham's *Catalogue of Indian Earthquakes from Earliest Times to the End of A.D. 1869.* Starting from the Cachar earthquake of 1869 the Geological Survey of India had devoted considerable attention to this subject. Mention should be made particularly of R. D. Oldham's memoir of the great earthquake of 12 June 1897 and the impetus he gave to the science of seismology by his discovery of the three main types of earthquake waves. Count F. de Montessus de Ballore's memoir entitled *The Seismic Phenomena in British India and their Connection with Geology* deals with the stability of various parts of India. As a result of researches it has been established beyond doubt that certain parts of India are more susceptible to earthquakes than others.

Special Expeditions: The Himalayas were the target of scientific expedition from the days of Mallet, Theobald, Stoliczka *et al.* These expeditions helped

in unravelling the geological myths on the origin, structure, stratigraphy, fauna and flora, and climate (past and present) of the Himalayas. Besides the expeditions conducted by Yarkand Embassy (1873), Afghan Boundary Commission (1896), and Sino-Burma Boundary Commission (1937), the more important ones are Tibet expedition (1920), Hukong valley expedition (1920), Abor expedition, Everest expedition (1921), and Mishmi Hills expedition (1934).

Contributions of other Organizations: Apart from the Geological Survey of India, geological studies were carried out by some erstwhile State organizations, universities, and private companies. The departments of the then princely States of Baroda, Rewa, Mysore, and Hyderabad conducted independent surveys. The earliest among them was the geology department of Mysore State organized in 1898. Its records covered such subjects as iron ores of Malavalli, Talpargi springs, laterite in Kolar, asbestos near Bangalore, magnesite in Mysore, and gold in Hole-Narsipur.

At Calcutta the Mining, Geological and Metallurgical Institute of India was established in 1906. The Geological, Mining and Metallurgical Society was set up in 1924. These organizations regularly published papers and journals dealing with geological and mining problems. The Indian Science Congress Association was founded in 1913, and the Congress sessions gave importance to geological problems by organizing a separate section. The Indian Mining Association was constituted in May 1892, and the Mining Federation was established in 1919.

IMPORTANT GEOLOGICAL CONCEPTS

We may now turn to some of the more important contributions to Indian geology made during the period covered in the preceding pages. These relate to (1) Origin and Evolution of the Himalayan Mountains; (2) Concept of Isostasy; (3) Concept of the Gondwana Continent; (4) Studies in Modern Seismology; (5) Granulite Facies Rocks; (6) Origin and Evolution of the Gondwana Basins; (7) Infra-Plutonic Shell; (8) Archaean Rocks; (9) Deccan Trap Volcanism; and (10) Basin Volcanism.

Origin and Evolution of the Himalayan Mountains: The Himalayas with the Alpine mountain ranges of Europe form one of the most important and grand features of the earth. From the time Herbert prepared the geological map of a part of the western Himalayas in 1825, large tracts in the Himalayan area have been mapped in some detail, as a result of which ideas have developed about the origin and evolution of these great mountains. It was generally assumed that the Indian shield remained passive while the Tethyean basin to its north was thrust against and over its edges. The foredeep to the south of the Himalayas was conceived to have been due to the buckling down of

the crust. But Lake pointed out the difficulty in such a concept. On the basis of gravity anomaly interpreted by Burrard indicating that there is no excess mass in the region of the Himalayas, the idea of origin of the Himalayas got modified to a northerly movement of the Indian shield thrusting the sediments of the Tethyean basin over the whole of its northern border.

The northerly movement of the Indian shield was noted to have caused the syntaxial bends in the north-west and north-east parts of the Himalayan mountains. A classic work on this by D. N. Wadia is well known. The origin and evolution of the Himalayas have a great significance in the global concepts on the origin of mountains.

Concept of Isostasy: The concept of isostasy owes its origin to the Great Trigonometric Survey of the Himalayan mountains. During the pendulum surveying, the differences which were glaring in the observed and inferred values of gravity at Dehra Dun and Murree amounting to 36 and 86 seconds of arc and 12 and 45 seconds of arc respectively were referred by Waugh (the then Surveyor-General of India) to Archdeacon Pratt of Calcutta, as a result of which Pratt propounded the theory of mountain compensation.

Concept of the Gondwana Continent: The 'Gondwana Continent' is named after the kingdom of Gonds, a great and ancient tribe which inhabited the area. The name was applied by H. B. Medlicott in 1872 to certain rock formations in parts of Madhya Pradesh where they were studied first. The importance of these rock formations in bearing coal deposits of the subcontinent was realized and the name became familiar in international literature. The rock formations being common, the southern continents were later recognized as parts of an original large continent, the 'Gondwana Continent', when the name actually found a permanent place in the theories which tried to explain the origin and evolution of the large-scale features of the earth.

Studies in Modern Seismology: The name of R. D. Oldham, Richter noted in his *Elementary Seismology*, 'is associated with much pioneer work during the years when seismology was passing from the pre-instrumental periods into the era of the seismograph. As head of the Geological Survey of India, he directed and personally carried out most of the investigation of the great earthquake of 12 June 1897. His monograph is one of the most valuable source books in seismology'.

Aspects of seismology like the determination of intensities and drawing of iso-seismals; estimation of displacement, velocity, and acceleration; investigation of the meizoseismal area; and study of seismograms and hypothesis on the cause of earthquakes were presented by Oldham and the impact of those early observations in the development of modern seismology and study of the interior of the earth is something extraordinary.

That the velocity of the seismic waves varies while travelling in different

kinds of strata is a concept of great importance. This was in later years utilized to arrive at the inferred structure of the earth and also in seismic surveys to reveal the sub-surface structures, especially in oil-field development.

Granulite Facies Rocks: At the turn of the century Holland introduced into petrological literature the name 'Charnockite', the implications of which are becoming more and more clear in the establishment of Pre-Cambrian stratigraphy. The term was originally applied to the bluish granite containing hypersthene, but later Holland opined that these rocks formed a distinct petrographic series. Studies in about 1947 supported that the Charnockites were petrographic series showing calc-alkaline trends. Subramaniam observed later that they did not conform to a petrographic series and he redefined these rocks. Now they have been understood to be the essential rocks of the granulite facies of metamorphism, and their recognition in other shield areas of the earth, specially with an age varying from 2,800 to 3,000 million years, has considerably influenced concepts on the evolution of the Pre-Cambrian geology.

Origin and Evolution of the Gondwana Basins: The realization that the distribution of the Gondwana basins was confined to certain well-defined zones warranting their deposition in a trough under fluviatile conditions, and of the climate of the Gondwana period starting from a glacial epoch and ending in more arid conditions has made possible the correlation of similar formations elsewhere in the world. This concept has also contributed to the theory of continental drift based on implications of extensive glaciation in such low latitudes. The Gondwana concepts have also led in turn to the concept of polar wanderings or shifting of poles through the geological ages.

Infra-Plutonic Shell: L. L. Fermor introduced the concept of infra-plutonic shell especially based on his studies of garnet and the Deccan Trap volcanism. He put forward the concept of a continuous basaltic shell of the earth, the plutonic equivalent of which is gabbro. Eclogite being the high pressure form of gabbro, Fermor proposed the existence of an infra-plutonic shell of eclogite. In this connection garnets were considered to be the geological barometer. Further, he also observed that the density and elasticity of eclogite and peridotite were close; but he preferred the concept of infra-plutonic shell of eclogite, basing his position on the fact that nodules of eclogite occurred in the kimberlite pipes of South Africa from great depths.

Archaean Rocks: Realizing the unusual difficulties in the problem of correlation of the Archaean rock formations like the absence of fossils and destruction of original characteristics by metamorphism, Fermor made perhaps the earliest attempt to correlate the Archaeans of the Indian shield. He first proposed a set of criteria based on which the Archaean rocks could be correlated. To this day they are found much useful. The criteria for correla-

tion which he proposed—stratigraphic continuity, structural relationship, history of igneous intrusions, associated ore deposits, lithological composition, chemical composition, grade of metamorphism, and radiometric age—are still essential evidence on which Archaean rocks are correlated. Thus the credit for the concept of correlation specially in the Archaean rocks goes undoubtedly to Fermor.

Deccan Trap Volcanism: The basaltic traps of the western part of the Indian shield were studied by Fermor in great detail. Occupying an area of about 200,000 sq. miles and having a thickness of over 7,000 feet, the basaltic trap rocks are considered as the most extensive geological formation of the Indian shield, second only to the metamorphic and igneous complex of the Archaean age.

Examining the rocks from a bore hole core which was driven through the trap rocks at Bhusawal to a depth of 1,217 feet, Fermor recognized some twenty-seven flows with an average thickness of 40 feet. The flows have great superficial extension compared to their thickness, and individual flows have been traced for distances of 60 miles or more. This extraordinary spread was explained by Fermor as due to a high degree of superheat in the mass. He developed the concept of eclogitic shell based on these studies.

The evolution of the Deccan Traps in time and space has been a very important problem. Their chemistry is typical of continental basalts and varies in silica content from 43 to 73 per cent. The stupendous volcanism which marked perhaps the end of Cretaceous and the beginning of Tertiary is a marvel of geology. The Deccan volcanism, however, has influenced the grand concept of fissure eruptions.

Basin Volcanism: Amongst the post-Archaean basins, the Cuddapah basin in the southern part of the Indian shield with its impressive igneous history has in recent years given evidence of basin volcanism and economically important mineral deposits. The idea of Karunakaran that the acid volcanic flows lead to extensive mineral deposits through replacement of silica by barium in shallow levels is a recent one. The bedded deposits of barytes of economic importance in the Mangampeta area have been attracting great attention.

MINING

Agriculture and mining are the two basic industries which flourished in ancient India as elsewhere. Iron, copper, tin, gold, and silver had been mined from very early times. These ancient mines have left their marks in many parts of India, of which an example is the Kolar gold-fields which reach a depth of some 300′. In striking contrast to this, modern engineers have successfully operated to depths of almost two miles below the surface. Another ancient

mine is at Khetri in Rajasthan for copper workings. Similarly, the lead-zinc workings of Zawar, also in Rajasthan, are of considerable historical significance, of which some operational details are available.

Coal: In modern times serious mining operations in India started with the finding of coal. Coal-mining dates back to the seventeenth century. The first true workings were recorded by William Jones in 1774 in the vicinity of Damalia near Raniganj where coal was extracted from shafts. The location of coal-mines in early days was determined by the proximity of river transport. In 1814 the Marquis of Hastings ordered an investigation of the coal resources of the country. In 1851 the East Indian Railway extended its track into the Raniganj and Jharia coal-fields, facilitating the development of the mining industry in this area. By 1860 nearly fifty collieries were producing about 282,000 tons of coal per year in the Raniganj area. In November 1864 a large area of the Raniganj mines collapsed and fire broke out in the area in March 1868. Oldham acted as a consultant and made recommendations on the collapse and fire. He urged that proper mine plans be kept, that the coal be cut by machinery, and that the panel system of working be adopted. Had Oldham's advice been heeded the loss due to fires and collapses would have been much less.

Coal-mining in central India dates back to 1862. The Singareni coal-fields in Hyderabad were discovered in 1872 and went into production fifteen years later. Development of coal-mining in upper Assam started in 1881 and that in Baluchistan (now in Pakistan) and the Punjab (in areas now in Pakistan) in the last decade of the nineteenth century. By 1906 Jharia coal output exceeded that of Raniganj. With the extension of the East Indian Railway from Barakar to Dhanbad and then southwards to link up with the Bengal Nagpur Railway, the development of the Jharia field proceeded apace. The Giridih and Daltongunj fields, in both of which the Bengal Coal Company had mines, were also increasing production.

The mining conditions in the Jharia field were favourable to easy development at cheap cost and the quality of many of the seams was superior to that of all but the best of the Raniganj seams. The mine owners in Raniganj had to face intense competition from the Jharia coal-field and perforce they had to develop the high-grade Deshergarh, Sanctoria, Poniati, and Chanch seams. The Raniganj owners were forced to adopt the cheapest mining methods possible. Early methods of mining were not very sound. This led sometimes to serious accidents causing loss of lives and coal. Alarmed at this loss, the Government of India passed the first Indian Mines Act in 1901 and created a new department of mines in 1902 with three inspectors headed by a Chief Inspector. The provisions of the Indian Electricity Act and Indian Explosives Act were also applied to coal-mines a few years later. The increased demand

for coal during the World Wars gave further impetus to the coal industry. Pillar working in thick seams, cutting of coal floors, traffic and pumping arrangements in the mines, and the panel system of inclined haulage were some of the measures introduced with the mechanization and electrification of mines. In 1970 the turnover of coal in India was 72,614,000 tonnes.

Gold: John Warren visited the Kolar gold-fields in 1802 in connection with the demarcation of the old Mysore State boundary and took up gold prospecting. This was followed by attempts of many firms, most of which proved very costly failures. From 1875 serious attempts to open up the mines were made, resulting in the 'gold boom' of 1880. Numerous companies were floated to prospect and operate the gold-mines in Wyanad, Kolar, Dharwar, Raichur, Ramagiri, and Gooty near Anantapur. Several other smaller fields in Mysore (like Bellara, Ajjanhalli, Kudrekonda), Tamil Nadu (like Hadabanalta and Bensibetta), and Andhra Pradesh (Bisanattam) were prospected and studied. By 1926 most of the fields ceased operation except the Kolar gold-field which survived as a profitable venture. In 1937 the Hutti gold-field was prospected again and reopened by the Nizam State Government. Later attempts to reopen the mines at Wyanad (1943-53), Gadag (1939-55), Bellara (1943-54), and Bisanattam (1950-61) ended in failures.

In 1878 the gold-mines of Wyanad were run into the slopes of small hills or into the sides of the great Cherrum. Sometimes adits and tunnels were driven. Quartz was crushed by stamping engines driven by batteries of 15 H. P. A 400-foot wire rope stretched from the entrance of the gallery to the works, along which baskets of vein stuff were shot to a kiln where the stone was burnt prior to being more easily broken up and tipped into a feed box. The gold was then concentrated in copper tables by the amalgamation process. In the present century mechanization and improvement in the underground mines of Kolar were carried out. In 1901 the Kolar gold-fields were worked at a depth of 1,000 feet by vertical shafts and hauling was done by means of crooked inclined shafts. The operating gold-mines in India today are only those at Kolar and Hutti. The production of gold in 1970 was 3,241 kg.

Copper: In 1831 the Indian Copper Mining Company was formed at Madras, but was apparently unsuccessful. The Hindoostan Copper Company was established in 1862. Agnigundala came into prominence as early as 1874 when Heyne referred to the existence of copper mines there. King in 1872 mentioned the stains of malachite on quartzite, and Foote likewise recorded the occurrence of copper in traces in the form of malachite and azurite films on the surfaces of quartzites, describing the mines as having been abandoned even then. At Baragunda in Hazaribagh district old mines extended over an area three-fourths of a mile in length and twenty-five to thirty yards in breadth. An attempt to work them was made by the Bengal Baragunda Copper

Mining Company formed about 1884, but the enterprise was abandoned in 1893.

Indigenous mining of copper was practised in the Darjeeling district of West Bengal about a century back. The miners made shallow excavations wherever they located the mineral chalcopyrites, abandoning them when the mines became uneconomical. The ore taken out from these mines used to be smelted locally; so at many places slags from these smelters are noticed.

The copper deposits of Dhalbhum and Singhbhum were discovered after 1820 and were mentioned by Jones in 1833. These occurrences, eighty miles in length, are riddled with outcrop excavations, shafts, trenches, etc. The ores were carbonites, pyrites in country rocks of mica schist, quartzite, quartzo-felspathic grits, talcose schists, etc. The copper content varied from 1·46 to 35·03 per cent. Traces of gold and silver were associated with the ore. The Indian Copper Corporation started production from 1927. For better exploitation of the copper resources of the country the Government of India set up a public sector company, Hindusthan Copper Limited, which was entrusted with developing Rakha mines in Bihar. Copper mines of India yielded 9,311 tonnes of this metal in 1970 against a requirement of 85,000 tonnes.

Iron: Every early attempt in India to graft European methods into the local processes of smelting iron ores on a large scale proved abortive. In 1830 the Indian Steel Iron and Chrome Company was established by J. M. Heath with its works at Porto Novo in South Arcot district, Madras, where ores from Salem district were smelted. Pig iron from the Porto Novo works was used in the construction of the Britannia Tubular and Menai bridges in England. The concern was closed down in about 1867.

The story began in Bengal in 1778 when the East India Company granted the right to manufacture iron in Birbhum district to Messrs Farquhar and Motle. Mackay and Company started production on a small scale at Mohamed Bazar, Birbhum district, in 1855. The Kumaun Iron Works was erected at Naini Tal in 1857, but it soon failed. Charcoal was used as smelting fuel until 1875 when advantage was taken of coke made from Indian coal. The Kulti Iron Works began producing pig iron in 1875. In 1889 these works were resold to the Bengal Iron and Steel Company. With the discovery of the hematite deposits of Gurumahisini, the Tata Iron and Steel Company was established at Jamshedpur in 1911. Mining operations had started in Bihar in 1904, and in Orissa at Mayurbhanj in 1911 and at Keonjhar in 1927. The Indian Iron and Steel Company, Burnpur, was inaugurated in 1922 and the Bhadravati Iron Works in 1933. The Indian Iron and Steel Company has been exploiting since 1938 the deposits of Pansura Buru and Buda Buru in Singhbhum. The ores of Badia Buru range have been quarried since 1923. The Noamundi mine of the Tata Iron and Steel Company was

discovered in 1917. Iron deposits in India were estimated in the seventies at 11,470 million tonnes. The total output of iron ore in 1980-81 was around 40·7 million tonnes.

Manganese: In 1833 Jenkins became the first to locate manganese ore in Madhya Pradesh in the crystalline limestone of the Pench river and to the north of Kumari in Nagpur district. In 1884 C. W. McMinn was the first to make an attempt at working a deposit; this was made in Jabalpur district, Madhya Pradesh. W. H. Clark and Harvey Dodd of the Vizianagram Mining Company started prospecting in 1899-1900 in Nagpur where several new deposits were brought to light. The Central Provinces Prospecting Syndicate was formed to prospect these deposits and it extended the operations to Chindwara, Bhandara, and Balaghat districts. The success that attended the Syndicate at the outset led others to prospect the belt. Subsequently mining operations were extended to other parts of the country. Two hundred manganese mines were working all over India in 1969 with an output of over 1·6 million tonnes.

Bauxite (*Aluminium*): In 1807 F. Buchanan gave the name laterite to a remarkable, ferruginous, residual rock which he had come across during his travels along the Malabar coast. Two types of laterite—high-level (primary) and low-level (secondary)—were distinguished by Mallet in 1883. A comparison was made by Mallet between the so-called Irish bauxite and the Indian laterite with regard to a possible similar mode of formation. F. J. Warth proved in 1903 that most varieties of laterite from Bihar, Bombay, Madras, Vindhya Pradesh, and Madhya Pradesh were in reality bauxite. C. Fox's memoir on the bauxite and aluminium laterite of India appeared in 1923. High-grade ore was also found to occur in Rewa and low-grade deposits in Gujarat and central India. Quarrying for bauxite started in the Katni district of Madhya Pradesh in 1908, in the Khaira district of Gujarat in 1920, and in Bihar in 1946. Good deposits of bauxite have been located in Ranchi and Palamau (Bihar); in Sarguja, Raigarh, Jabalpur, Shahdal, Bilaspur, Durg, Balaghat, and Mandla (Madhya Pradesh); in Kolhapur and Kolba (Maharashtra); in Belgaum (Karnataka); in Salem (Tamil Nadu); in Sambalpur and Koraput (Orissa); and in Saurashtra (Gujarat). In 1970 the total output of bauxite was 1·36 million tonnes.

Chromite: Chromite ores were discovered in Mysore by E. Slater (1898), in Baluchistan by E. Vredenburg (1901), and in Singhbhum (Bihar) by R. Sanbolle (1907). Mining operations began in Baluchistan in 1903. This was followed by chromite mining in Mysore and Singhbhum in 1907 and 1909 respectively. Over 40 per cent of the total of India's chromite production has come from the Mysore and Hasan districts of Mysore (now Karnataka) State. Large ore bodies were discovered in Orissa in 1943. The exploitation of

chromite deposits in Andhra Pradesh has assumed some importance since 1948. The production of chromite in India was estimated at 270,879 tonnes. The estimated reserves of this mineral are placed at 111·2 million tonnes.

Lead, Zinc, and Silver: Prospecting for lead, zinc, and silver in Rajasthan was done presumably by the State in 1872. Long before this, lead deposits near Ajmer had been worked for many years and an annual production of 14,000 maunds had been attained. The mines were closed on the eve of the Sepoy Mutiny (1857). Lead and zinc ores are found in Udaipur, Jaipur, and Ajmer (Rajasthan); in Riassi (Jammu); in Almora (Uttar Pradesh); and in Cuddapah (Andhra Pradesh). In 1942 the Eastern Smelting and Refining Company took on lease an area, about sixty-four miles from Jaipur, containing lead deposits. This mine was extensively prospected and about 12,000 to 15,000 tons of mainly lead carbonate ores were raised. The company had also simultaneously installed a smelter on a pilot scale in the coal-fields of Tundoo in the Manbhum district of Bihar. A few hundred tons of lead were smelted in the following three or four years. This may be considered as the beginning of the lead mining and smelting industry in India on a commercial scale. In 1970 the production of zinc was 23,410 tonnes, that of lead and silver being 1,862 and 1·5 tonnes respectively.

Mica: Mica mining in India started about the first quarter of the nineteenth century, if not earlier. From 1884 mica exports were more or less regular. Towards the close of the nineteenth century there was rapid development of the electrical industry in the United States and Germany. The demand for mica as an insulator for electrical and heating purposes grew by leaps and bounds, stimulating an increase in the production of mica.

F. F. Chrestien played an important part in the development of mica mining in the late nineteenth century. By 1899 his company operated 110 mines in Tisri, Bairia, and other places. Before 1900 manufacture of splittings had begun, revolutionizing the mica business. But mining methods were still primitive. In 1910 modern mining was introduced under Chrestien's guidance. In 1970 the production of mica was 22,915 tonnes.

Diamond: Until the discovery of diamonds in Brazil in about 1725, India was the world's only supplier of these gems. Most of the great historical diamonds such as Kohi-i-noor, Pitt (or Regent), Hope, Orloff, Florentine, and Dresden Green are of Indian origin. Tavernier, who visited India in the seventeenth century, refers to diamond mining activity in the Deccan. Many of the diamond mines were situated in south-eastern India in Andhra Pradesh from where most of the world's big diamonds came.

Although there were many active workings of diamond deposits during the earlier part of the nineteenth century, diamond mining gradually came

to an end in South India, the last recorded return of a trivial quantity being in 1913.

But diamond mining continued in central India. The principal producers of diamonds in the Bundelkhand tract at the present time are the Panna Diamond Mining Syndicate, the Mahalaxmi Diamond Mining Works, and the Charkhari Mining Works, the last of which operates a large open-cast mine near Ramkheria. From this mine diamonds of the value of Rs 350,000 approximately were recovered in 1952. The Panna Diamond Mining Syndicate commenced operations in 1936, but owing to the war and other causes little beyond prospecting was possible before 1949. Between 1936 and 1950 the Syndicate recovered 23,653 stones of a total weight of 16,152 carats.

Sapphire and Corundum: The sapphires of Kashmir form an exclusive class. The best among them are an intense cornflower blue with a rich velvety lustre and a tenuous milkiness spreading over the surface and adding greatly to the charm of the stone. Discovered by accident about 1881, the gem first came on to the Indian market about 1882. The mines are 2½ miles west-north-west of Sumjam in the Podar area of Zangskar at a height approaching 15,000 feet on the southern slopes of the Zangskar Range below the Umlasi Pass. The whole area remains under snow for the greater part of the year. La Touche visited the working in 1888. For some years after this the Kashmir Durbar derived considerable revenue from them before they were abandoned under the erroneous impression that they had been worked out. In 1906, however, work was resumed by the Kashmir Mineral Company. Several valuable stones were obtained, one of them being sold for £2,000. By 1908 mining operations had ceased due to the inaccessibility of the location and its rigorous climate. In 1927 the area was again worked with good results, 11 cwt of corundum having been obtained. Systematic work commenced again in 1933 and from that time until the end of 1938 the annual average production was 641,656 carats of sapphire.

Oil: Oil shows occurring on the Budderpore Tea Company's estate at Cachar in Assam encouraged the drilling of a shallow well as far back as 1901. This led in 1910 to a geological examination and the location of a test well. Two wells still did not go deep enough, but late in 1915, when another well reached an oilsand at 820 feet, a new oil-field was found. By 1933 the yield had fallen so low that the value of the oil failed to meet the cost of obtaining it.

In upper Assam there were many oil seepages, but geological mapping of the exposed areas revealed few structures suitable for retaining oil. However, when surface structures failed to yield oil, attention was turned to structures completely hidden beneath the alluvial deposits of the Assam valley. An early attempt (1925-28) to locate these structures by a gravity

survey was not successful, but it did lead later on to the initiation of a seismic survey which indicated the Nahorkatiya structure on which a test well was drilled in 1952-53. Oil was found in several sands between 9,400 and 10,200 feet. These new oilpools were developed later on.

The first account of the geology of the Digboi field was given by E. M. Pascoe, showing that in 1911 only the barest outline of the geological structure was known. Initially, the Digboi oil-field was worked in a small way for some fifteen years. Production slowly crept up from 200 to 300 barrels per day and from 1916 to 1922 averaged about 350 barrels per day, by which time about 100 wells had been drilled.

The first Digboi refinery was a very simple affair for distilling the crude oil to get kerosene and also a heavy fraction to yield wax through cooling. Petrol was a waste product for which there was no demand. It has been said that no refinery is ever complete. Improvements were made from time to time, especially in the early twenties, and the building of an entirely new and enlarged refinery including a cracking plant was completed in 1931. An Edeleann plant which uses liquid sulphur dioxide to remove aromatic compounds from kerosene, thereby improving its burning quality, was added in 1932. Since then the principal additions have been two modern crude oil distillation units—a lubricating oil distillation unit and a plant for extracting gasoline from natural gas.

The importance of the role played by geology and mining in India can be gauged from the pace of industrialization as well as technological and scientific progress since the time of the East India Company's rule to the dawn of independence in 1947. Geology and mining are closely related. To any country not largely built on alluvium, systematic geological survey operations are of great importance to promote not only mining but also engineering and agriculture. Geological surveys are of help in the construction of dams, reservoirs, and roads; in the location of underground water sources; in predictions of earthquakes; and in the supply of raw materials for metallurgical industries. These are all vital to the development of the country.

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GEOPHYSICS

THE beginnings of geophysics in India can be traced to Col. William Lambton who proposed in 1799 a trigonometric survey of the southern peninsula to study the eartl 's ellipticity. This resulted in a geodetic triangulation network which commenced in 1802 along the central meridian (77° 30′). India provided the first valuable data to propound the concept of isostasy through the work of Archdeacon Pratt, who made quantitative estimates of the gravitational attraction of the Himalayas in 1852. The earliest work in seismology was that of T. Oldham published in 1883 entitled *Catalogue of Indian Earthquakes from Earliest Times to the End of A. D. 1869*. The first seismograph in India was installed by N. A. F. Moos at Bombay in 1898.

Geomagnetic studies in India commenced in 1826. The first geomagnetic observatory in this country, the second oldest in the world after Greenwich, was commissioned in Bombay in 1846. It was transferred in 1904 to Alibag, twenty-eight kilometres to the south-south-east of Bombay. Basevi and Heaviside conducted gravity surveys during 1865-73 using two brass pendulums, and set up thirty stations between Cape Comorin and the Himalayas. By 1939 there were 564 pendulum stations. The Survey of India carried out the first magnetic survey in 1901. In the fields of applied geophysics and geophysical prospecting, the earliest work was that of Steichen and Sierp, who measured the radioactivity of some mineral springs around Bombay during 1911-13.

Pioneering studies by George Simpson of the India Meteorological Department (IMD) from 1907 onwards led to the 'breaking drop' theory of electricity of thunder-clouds in the area of atmospheric electricity. In the field of oceanography the first expedition was led by John Murray in 1933-34 resulting in the collection of information about the topography and deep-sea oceanography of the Indian Ocean. Studies in other areas like hydrology, volcanology, and terrestrial magnetism were carried out in India in the nineteenth century itself, although they did not have the distinct character of what has now come to be recognized as geophysics.

The Survey of India and IMD have to their credit many pioneering efforts in the fields of geodesy, seismology, and terrestrial magnetism. The first adjustment of the triangulation of India was done by the Survey of India in 1880 and revised in 1937. The general gravity survey carried out by the Survey of India during 1906-39 as a scientific problem provided a fairly complete picture of major regional anomalies of the gravity field of India

and Burma. The Survey of India acquired a Frost gravimeter in 1947, a geodetic Worden gravimeter in 1953, and an improved model of Lacoste and Romberg gravimeter in 1963 with a view to having stations at spacings of 15 km. or less in selected regions. So far, about 14,000 stations have been covered throughout the country.

IMD had a network of seismological observatories of eye-reading type at Simla, Calcutta, Kodaikanal, and Agra. During the period 1922-25 they were improved to sensitive photographic reading instruments of Milne-Shaw type and extended to Hyderabad. The Department has been publishing data about 'felt' shocks since 1908. Oldham's classic memoir on the great Assam earthquake of 1897 gave a general impetus to the study of seismology all over the world. About the same time the Geological Survey of India (GSI) also started scientific investigations on the geological structure of the country based on earthquake data. Discreet studies were thus being carried out by GSI, the Survey of India, and IMD by about 1938. The need for a co-ordinated study of seismology was keenly felt in order to keep abreast with the latest researches elsewhere in the world.

GEOMAGNETISM AND GEOELECTRICITY

India has a long history of geomagnetic observatory operation and land magnetic survey and research. The earliest observations of the three elements of the earth's magnetic field began, as already mentioned, at Bombay in 1846. The measurements were carried out by an extremely laborious method of observing absolute field with optical instruments round the clock at hourly intervals. This system continued for about twenty-five years till 1871 when photographically registering variometers were installed. The magnetic observatory continued to function at Bombay until 1904 when, consequent on the introduction of tramways, it was shifted to Alibag. To connect the long series of Bombay observations with those of Alibag, magnetic observations at both the stations were made simultaneously for a further period of two years before the Bombay magnetic station was closed. The Alibag observatory has continued to provide the scientific community with magnetic records and uncontaminated magnetic data since 1904. Bombay-Alibag photographic variometer records now encompassing over a century have a unique place in the magnetic archives of the world.

The early part of the present century was marked by some outstanding research work. Moos of Colaba observatory, Bombay, analysed and discussed the extensive Bombay magnetic data for the 60-year period, 1846-1905. His results, published in two volumes in 1910, constitute an exceedingly valuable contribution to the study of magnetism in the early part of the century. Other significant contributions to research were made by John Allan Broun, who

discussed the magnetic observations at Trivandrum and discovered the 27-day periodicity in the daily variation of the field. Broun, in association with Charles Chambers of Colaba observatory, also studied the daily lunar variations of the earth's magnetic field. The 27-day oscillation of the field, associated with solar-synodic rotation, has been the subject of numerous investigations and is still of interest. Similarly, the semidiurnal lunar variations in the field still remain a subject of active research.

But for the early contributions of Broun, Chambers, and Moos, observational and research work in the field of geomagnetism in the country remained static in the first half of this century with Alibag as the only observatory in operation. A magnetic observatory operated at Kodaikanal from 1901 by the Survey of India was closed in 1921. It was revived in 1948 when magnetic work commenced at the station for co-ordinated solar-magnetic-ionospheric studies. A significant step in the expansion of geomagnetic work in the country was taken in 1957 when two equatorial stations—one at Trivandrum, close to the dip equator, and the other at Annamalainagar—were established as part of the Indian programme for the International Geophysical Year 1957-58. A further strengthening of the surface magnetic network in India came about in 1964 when the Hyderabad observatory of the National Geophysical Research Institute (NGRI) went into operation. In 1964 the Survey of India also established a magnetic observatory at Sabhawala, Dehra Dun. The geomagnetic surface network now consists of six observatories, three of them located within the equatorial region.

Recent years saw considerable progress in geomagnetic and geoelectric work. In the field of research the Institute of Geomagnetism at Bombay, NGRI at Hyderabad, and the Physical Research Laboratory at Ahmedabad made notable contributions. The Institute at Bombay participated in an international project sponsored by the International Association of Geomagnetism and Aeronomy at the initiative of the late Professor Sydney Chapman. This project, called World Magnetic Archives, envisaged tabulation in machine-readable form of a long series of magnetic data collected from Bombay, Alibag, Oslo, Greenwich, Melbourne, Leningrad, and other old and established observatories.

The Survey of India, through its geodetic and research branch, did pioneering work in magnetic surveys. By 1967 repeat stations located from 200 to 300 km. apart and field stations at a spacing of 20-30 to 60-80 km. were established for measurement of the three elements of the earth's magnetic field and the whole country was covered by repeat and field surveys. One fruitful result of these surveys was that, after reduction, basic data for the computation of secular variation of the field as well as for preparation of magnetic charts became available. In the post-independence period the Survey of India

established four repeat stations and twenty-two field stations in the Andaman-Nicobar and Laccadive Islands.

SEISMOLOGY

The study of earthquakes was in the hands of GSI before instruments were introduced towards the close of the nineteenth century. Field investigation reports on earthquakes nevertheless contained valuable information regarding damage, its relationship with the distance from the epicentre of the earthquake, with the local geology, etc. Seismological instrumentation was introduced in the country in 1898, and observatories were started first at Bombay, Calcutta, and Kodaikanal (Madras), and later on at Simla. IMD was entrusted with the running of the seismological observatories and the utilization of the data for analysis and dissemination. The observatories were started with Milne seismographs, which were replaced in the 1920s by the superior Milne-Shaw seismographs. The tempo of seismological work did not change till 1947, and all that the country had was the above-mentioned four observatories and another co-operating observatory at Hyderabad. For these five observatories there was only one whole-time officer working in seismology in addition to the occasional utilization of the officers of GSI for field studies. The number of seismological observatories has since increased to over fifty. The instrumentation at the observatories has also seen rapid modernization. Compared with the Milne-Shaw seismograph with a magnification of 250, most of the observatories are now operating with electromagnetic seismographs with magnifications reaching 100,000.

A number of earthquakes affected the country during the post-independence period. The Assam earthquake of 1950 was followed by a large number of aftershocks. This event was studied in very great detail by both seismologists and geophysicists. Among the other notable earthquakes studied were those affecting the Manipur-Burma area (1954), Bulandsahr (1956), Anjar (1956), Delhi (1960), and Muradabad (1966), and three in the Deccan shield area. In contrast to the study of individual damaging earthquakes (in seismic zones), drawing their isoseismals, and forming a picture of seismicity, different approaches could now be made. Whereas the latest knowledge about the known high seismic belts in the Himalayas, Kutch, and the Bay Islands is confirmed, the ideas on the seismicity of the Deccan plateau have undergone a terrible shake-up. Geophysical studies following three major earthquakes at Koyna (1967), Bhadrachalam (1969), and Broach (1970) have led to a revision of the old ideas of the peninsula being free from earthquakes.

GRAVITY AND GEODESY

Reference was made earlier to the work done in India during the

nineteenth century in the field of gravity surveys. Steps were later taken for the establishment of a gravimetric calibration base in the country, leading to the setting up of the National Reference Station at Dehra Dun, which has a gravity value of 979·0640 cm./sec^2. During 1965-71, the Survey of India carried out half-hourly gravity observations over a period of thirty-one days for the study of earth tides at Dehra Dun, Bangalore, Jabalpur, Calcutta, Abu, and Shillong. Three more stations at Delhi, Bombay, and Madras were established in 1972. Further, to solve some problems connected with air travel forty-two important airports were covered by precession gravimetric observational loops in 1971-72. NGRI conducted a project for the preparation of a Bouguer anomaly map of the country by collecting gravity data from various organizations like the Survey of India, Oil and Natural Gas Commission (ONGC), and GSI, supplementing it wherever necessary by their own regional gravity surveys.

Further work in geodetic triangulation was carried out in the post-independence period bringing the total number of G.T. stations to 3,004. Local geodetic triangulations, base measurement, trilateration, and precise traverse have been carried out in various parts of the country for important industrial, hydroelectric, dam deformation, and irrigation projects, and also for geological investigations. On account of the vast area of the country, the basis for levelling data has been chosen as the mean sea level at nine tidal observatories selected with due regard to their configuration. The first level-net in India was started as early as 1858. By about 1912 improvements in technique and knowledge led to the need of levelling, called H.P. levelling. With this end in view, the second level-net of India was commenced in 1914. This new net has practically been completed except that a few weak connections are being revised and some connections are being made to tidal observatories which are functioning at the coast line. Its rigorous adjustment remains to be done pending re-evaluation of the Indian mean sea level.

The astronomical determination of latitude, longitude, and azimuth played an important role in the programme of survey work to give the necessary corrections to the angular observations due to the deviation of the vertical. The number of stations at which both components of the deviation of the vertical have been observed is nearly 1,700, and the number of Laplace stations is 159. The astronomical observatory at Dehra Dun is equipped with impersonal transits, a zenith telescope, and Shortt and Reifler pendulum clocks. A Danjon astrolabe and crystal clocks have also been acquired and installed.

PHYSICAL PROPERTIES OF ROCKS

Study of the physical properties of rocks, including elastic, magnetic, and

thermal properties, has also made considerable progress after independence. The elastic properties of sedimentary, igneous, and metamorphic rock types were studied from the point of view of density, porosity, composition, and pressure. Some studies were also made on the attenuation of signals in rocks, fracture strength of various rocks, and the mechanism of fracture. These studies threw some interesting light on the nature of compaction of various rock types and the mechanism of wave propagation in them.

Magnetic properties including natural remnant magnetization intensity, magnetic susceptibility, and Koenigsberger ratio were determined for a number of igneous and sedimentary formations. 'Hysteresis behaviour of basalts was studied in low as well as high fields. A new phenomenon in rocks known as 'magnetic memory phenomenon' was discovered. These studies threw some interesting light on the nature of soft as well as hard components responsible for magnetization in rocks. A highly sensitive apparatus was constructed for the study of magnetic susceptibility with temperature. Study of this property with temperature along with hysteresis studies revealed the nature of domain structure in magnetic minerals contained in rocks.

Thermal conductivities of a large number of rock types including sandstones, shales, claystones, phyllites, quartzites, schists, gneisses, and granites were studied for purposes of interpreting heat flow in geologically different areas. These studies provided new information on the variation of thermal conductivity with grain size, mineral composition, and water saturation.

GEOPHYSICAL EXPLORATION

The work of Steichen and Sierp in applied geophysics between 1911 and 1913 was followed up on a much larger scale by N. C. Nag and N. K. Chatterji during 1939-41. P. K. Ghosh of GSI also measured the radioactivity of the water of more than a hundred springs. When the success of applied geophysics was beginning to be appreciated, the Punjab Irrigation Research Institute carried out in 1927 bed-rock investigations using an Eotvos torsion balance. After the studies on mineral springs, the officers of GSI became interested in studying magnetic properties of certain manganese ores. Their interest increased at the beginning of World War II with the intensification of the search for strategic minerals.

The importance of geophysics as a tool for oil exploration was first appreciated in India by the Burmah Oil Company in 1923 when the first geophysical survey using a torsion balance was carried out in the Indus valley. Unfortunately, no oil was found when drilling was done on the basis of the results of the survey. The next survey was conducted in 1925 in Assam, again using a torsion balance, but the implication of its results was not fully understood at that time. This survey gave the first indication of a gravity high that

has now become famous as Nahorkatiya oil-field. In 1933 Messrs Piepmeyer-Kelbof carried out electromagnetic surveys in Nellore district (Andhra Pradesh) and later in Singhbhum (Bihar) for copper. The year 1937 was truly remarkable as it saw the first major geophysical survey for oil in India—over 250,000 sq. miles of alluvial tracts—by the Burmah Oil Company and the Anglo-Iranian Oil Company. Gravity and limited seismic reflection surveys were mainly resorted to, resulting in Assam oil finds in addition to some contribution to our knowledge of isostasy in India. The credit for the first geophysical survey (1937-38) by an Indian goes to M. B. Ramachandra Rao who carried out several electrical surveys for sulphide ores and graphite deposits in Mysore. He also reported studies in hydrology and engineering problems using geophysical methods. The first Indian to study geophysics was B. Sanjiva Reddy in 1935 at Colorado School of Mines under Heiland, followed by M. S. Krishnan in 1936 at Imperial College, London. During World War II the Geological Department of the Mysore State was the only organization to carry out geophysical work using self-potential and resistivity surveys, a work with which M. B. R. Rao was closely associated. Gulatee of the Survey of India, at the instance of GSI, carried out geophysical surveys for mica pegmatites and manganese ores during 1941-43. Interpretation of magnetic anomalies caused by bodies of known shape is another very valuable contribution made by Gulatee.

The initiation of geophysical exploration activities in GSI was largely due to the efforts of G. Dessau in 1945 when attempts were made to organize its geophysical wing. Soon the services of an Italian instrument technician, Delcarlo, were enlisted and a workshop for repair and maintenance of geophysical instruments was set up. This wing carried out a number of S. P. resistivity and magnetic surveys at different places. It was planned that this wing would also carry out surveys for engineering problems, water resources, metalliferrous and coal deposits, tectonic investigations for oil, etc.

Geophysical survey of the Cambay basin was launched in 1948. A magnetometer survey was carried out over 25,000 sq. km. in one season, but follow-up by gravity and seismic surveys had to be slowed down due to lack of instruments. By 1957, with the acquisition of a Worden gravimeter and a portable seismic reflection unit, the first test drilling on an anticlinal structure could be recommended with confidence. This is the first major success of Indian geophysicists in oil exploration. This has been followed by extensive studies in various parts of the country by ONGC.

The geophysical investigations conducted after independence have shed considerable light on the geology of a number of sedimentary basins of India. These have permitted a more objective assessment of the petroleum prospects in the country and have led to the discovery of a large number of oil and gas

fields. However, there still remain several difficult geophysical problems to be solved. These include the mapping of sub-surface horizons in the thrust zones and that of sub-surface configuration of the major anticlines in the folded areas of the Himalayan foot-hills and the Arkaan Yoma ranges. Another unresolved problem is that of obtaining persistent reflections from the post-Eocene formations in the West Bengal basin. The larger anticlinal structures in the Cambay basin have more or less been discovered. The exploration efforts are now directed to locate the litho-stratigraphic traps. Reliable seismic techniques have to be evolved to meet this requirement. One of the persisting problems in well log interpretation is that of fresh water shaly-sands. The interpretation of formations with complex lithology is another example. To solve the problems mentioned above it is necessary to design and fabricate indigenous sophisticated geophysical instruments and ancillary equipment with a view to considerably improving upon the seismic data. Also, much of the improvement in the data will be required to be done through processing. For this purpose, geophysical softwares involving multichannel processes and other advanced techniques have to be developed. Geophysical exploration and interpretation techniques rapidly struck roots in India after independence. All major exploration agencies like GSI, ONGC, and the Central Groundwater Board adopted these techniques in conjunction with reconnaissance geological studies in their exploration surveys for minerals, oil, and water, and in connection with engineering problems.

One of the outstanding contributions of the National Geophysical Research Institute (NGRI) was the development of expertise in instrumentation and interpretation relating to airborne geophysical surveys. NGRI developed a proton magnetometer and automatic recording unit which could be airborne or sea-borne and used it in aerial surveys carried out in Mysore and Madhya Pradesh on over 50,000 sq. km. The cost of these surveys was about one-fourth of the cost of surveys carried out by foreign agencies in India. Pioneering work in marine geophysical surveys on board INS 'Darshak' in the Arabian Sea was also conducted by NGRI leading to significant results relating to the well-known 'Bombay High'.

NATIONAL GEOPHYSICAL RESEARCH INSTITUTE

Geophysical research in India received a great impetus with the establishment of NGRI in 1962. Research groups were constituted to deal with problems in the disciplines of gravity and isostasy, geomagnetism, geoelectricity, geophysical instrumentation, physical properties of rocks, theoretical geophysics, geophysical modelling, palaeogeophysics, seismology, and geophysical prospecting. This institute has earned a great reputation in international circles, having published many research papers. In addition, a large

number of consultancy and other jobs were undertaken by it. As part of this research programme, seismological, geoelectric, and geomagnetic observatories were established. Geoelectric and seismological observatories are coming up in different parts of the country under the supervision of NGRI. One such geoelectric observatory is at Ettayapuram on the dip equator. The Institute undertook a deep seismic sounding project for crustal studies in collaboration with the U.S.S.R. and another project for management of groundwater resources in collaboration with the German Democratic Republic.

INTERNATIONAL COLLABORATION

The first major Indian participation in any international project was in the International Geophysical Year (IGY) from July 1957 to December 1958. This project was organized by the International Council of Scientific Unions (ICSU) to study the physics of the earth, its atmosphere, and solar-terrestrial relationships. This period was chosen because the sun, which affects life on earth and other geophysical phenomena, was attaining the climax of its eleven-year sun-spot cycle. The Indian National Committee formed in 1953 co-ordinated the Indian activities in all the fourteen disciplines included for study during IGY. Indian participation in the International Quiet Sun Year (IQSY) programme (1964-66) was also wide and extensive. Programmes were undertaken in the disciplines of meteorology, atmosphere, geomagnetism, cosmic rays, aeronomy, and solar activity. A major addition was the use of rocket sounding from the Thumba Equatorial Rocket Launching Station (TERLS) on the magnetic equator and a series of high altitude balloon flights.

Through the Geophysics Research Board, India actively participated in the International Upper Mantle Project (1965-70) which aimed at focussing the attention of all geoscientists to the problems of the interior of the earth. The principal objective of the project was to study the outer 1,000 km. of the solid earth. Universities, GSI, the Survey of India, IMD, NGRI, and other organizations participated in this programme. The first symposium on Upper Mantle Project was organized by the Geophysics Research Board, Indian Geophysical Union, GSI, and NGRI at Hyderabad during 4-8 January 1967. It took stock of the work done in the country and drafted plans for the remaining period of the International Upper Mantle Project. This symposium was a grand success judged by the reception accorded to the proceedings by international scientific bodies.

The Geophysics Research Board and NGRI also supported an international symposium on Deccan Traps and other flood eruptions in January 1969 at Saugar University, jointly sponsored by the University Grants Commission (UGC), GSI, and the International Association of Volcanology and Chemistry of Earth's Interior. A winter school was organized by the Indian

Geophysical Union in collaboration with the Geophysics Research Board and Atomic Energy Commission during December 1968 with a view to providing refresher courses in solid earth geophysics to research scholars and others in universities and Government research and survey organizations.

The second symposium on Upper Mantle Project was held at NGRI, Hyderabad, during December 1970 with the main objective of assessing the Indian contributions to this international project. All major organizations dealing with geophysics participated in the symposium and over 100 papers were presented. The programme for International Geodynamics Project (IGP), 1972-77, being successor to Upper Mantle Project, was also discussed. The objective of this project was to study the dynamic history of the earth with emphasis on deep-seated foundations of geological phenomena, specially, evidence of movements at depth. The Inter-Union Commission for Geodynamics Project constituted ten working groups of scientists drawn from different disciplines and geographical areas to co-ordinate activities in IGP. Seven Indian scientists found place on different committees and Hari Narain was nominated chairman of the Himalayan sub-group under working group No. 3.

CENTRAL BOARD OF GEOPHYSICS

The Government of India constituted a planning committee for geophysics in 1946 to deal with the organization and development of geophysics as a distinct discipline of earth sciences on a systematic basis. This was done because of the major role geophysics played in prospecting for oil and minerals in the country. Its importance to the study of earthquakes, volcanoes, and other natural phenomena was also recognized. The committee's main recommendations included plans for a co-ordinated development of geodesy, seismology, terrestrial magnetism, earth current studies, geophysical prospecting, atmospheric electricity, hydrology, and oceanography. The most significant recommendations included the establishment of a central geophysical institute, the formation of a national committee of geodesy and geophysics, and a standing committee for co-ordination. The Central Board of Geophysics (CBG) came into being in 1949. Its membership consisted of representatives from the Survey of India, GSI, IMD, Central Waterways, Irrigation and Navigation Commission, Central Board of Irrigation, and Indian National Science Academy. The headquarters of CBG was at Calcutta till 1962. Apart from co-ordination of various geophysical activities by different organizations, it was charged with the implementation of the recommendations for the establishment of a central geophysical institute. In April 1961 CBG with its constituent research wings was transferred to the Council of Scientific and Industrial Research (CSIR), resulting in the establishment of the National

Geophysical Research Institute in 1962 and the National Institute of Oceanography in 1964. The Central Board of Geophysics was renamed as the Geophysics Research Board (GRB) in April 1962. The establishment of NGRI is a landmark in organized geophysical research activity in India.

Andhra University and Banaras Hindu University started a post-graduate course in geophysics in 1949. The Indian Institute of Technology, Kharagpur, in 1952 and the Indian School of Mines, Dhanbad, in 1957 started courses in applied geophysics, thus fulfilling the long-felt need for trained geophysicists in the country. Subsequently, Roorkee and Osmania Universities also started courses in geophysics at the post-graduate level.

It is thus clear that India has been taking an active interest in geophysics right from the beginning of the nineteenth century and its utility has come to be recognized in the survey of natural resources. The Geological Survey of India, Survey of India, and India Meteorological Department were among the earliest scientific institutions to deal with geophysics. Several other institutions like the National Geophysical Research Institute, Hyderabad; Physical Research Laboratory, Ahmedabad; Tata Institute of Fundamental Research, Bombay; and Airborne Mineral Surveys and Exploration, New Delhi, have come up and are charged with important national tasks. With the growing demand for water, minerals, oil, and other energy resources, which are basic for man's survival and well-being, geophysics will doubtless play an increasingly important role in the years to come.

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METEOROLOGY

METEOROLOGY had not developed as a distinct science in India at the beginning of the nineteenth century. However, astronomical and magnetic observations as well as atmospheric phenomena like rainfall, monsoon, winds, tides, and temperature variations attracted the attention of scientists of various descriptions in the service of the East India Company. Eminent naturalists like William Roxburgh maintained records of rainfall in connection with their investigations into agriculture and plant life towards the end of the eighteenth century. About the same time William Petrie, an amateur astronomer, set up at his own expense an observatory in Madras in 1788. His instruments provided the nucleus for the Madras observatory which was established in 1792 by Michael Topping. This work received encouragement from Sir Charles Oakeley, astronomer, President of the Madras Council of the East India Company, and Governor of Fort St George. A granite pillar (Plate I) which carried Petrie's original transit instrument is still preserved in Madras as a monument.

Another observational activity, albeit of a different type, which later on came to be associated with the Meteorological Department, had also an early beginning. This was the setting up in 1823 of an observatory at Colaba (Plate II), a suburb of Bombay. This observatory specialized in geomagnetic surveys. Mention should also be made of an additional observatory established in Trivandrum in 1836.

Study of Tide and Cyclone: Around 1805 James Kyd started observations on tides in the Hooghly river and introduced a tide register which continued till 1828. In 1823 James Prinsep initiated an interesting study of the diurnal rise and fall of pressure in different parts of India. Henry Piddington, who came to India as Curator of the Calcutta Museum and later became President of the Marine Court, was a pioneer in the study of tropical storms over the sea. He introduced the word 'cyclone' to describe such a storm. Of Greek origin, the word means the coils of a snake and aptly describes the winds hurtling round a gigantic whirlpool. He wrote a series of memoirs for the then Royal Asiatic Society of Bengal on the cyclones of the Indian Ocean from 1839 to 1851 and *The Sailors' Handbook of Storms*, an indispensable guide book. These works were no doubt important contributions in the nineteenth century to the study of tropical storms. R. Everest studied the seasons of India and published a paper on the subject in 1835. He also published an account of droughts from 1831 to

1838. In 1848 attempts were made to record maximum and minimum temperatures over different parts of India. In the meantime, in 1829, the Survey of India had set up in Calcutta an establishment for carrying on meteorological observations.

These early observations of weather in India are of considerable historical interest. They suffered, however, from serious lacunae inasmuch as they were not recorded at the same time, and there was little by way of uniformity in instruments or records. Thus it was impossible to form from such sporadic observations an integrated picture of the prevailing weather or its fluctuations.

The Sepoy Mutiny of 1857 led to the suspension of meteorological observations between 1857 and 1860, but there was a revival of interest around 1861 largely through the efforts of the Royal Asiatic Society of Bengal which was formed in 1784 by Sir William Jones for the development of science in Asia. In the post-mutiny period one of the prominent members of the Society, Col. R. Strachey, appointed a committee for organizing meteorology in India. Through his initiative, the committee drew up a development programme which was estimated to cost Rs 67,600. The committee warned the Government that 'any attempt to obtain meteorological data on a cheap scale will fail' and that 'any expenditure which is so incurred will prove a loss of money'.

Natural Calamities—Need for Warning System: Towards the second half of the nineteenth century a number of natural calamities and disasters struck the country. In October 1864 Calcutta was devastated by a severe tropical cyclone. A tidal wave moved up the Hooghly and inundated large tracts of low-lying land. It was estimated that 80,000 lives were lost by drowning or exposure. This cyclone was unfortunately followed a few weeks later by another which passed over Masulipatnam (now known as Machilipattanam). This took a toll of nearly 40,000 lives. These two disasters, coming as they did in quick succession of each other, caused much distress and concern to the shipping community. The Bengal Chambers of Commerce drew the attention of the Government to the absence of an early warning system against natural disasters.

In 1865 the Government of Bengal appointed a committee to draw up plans for a chain of meteorological observatories along the northern coast of the Bay of Bengal and at the port of Calcutta for warning the people about an approaching storm. The committee had H. F. Blanford, then Secretary of the Asiatic Society, as one of its members. About this time the Government also set up a commission for improving sanitary conditions in different parts of the country with Sir John Strachey as its President. Oddly enough, this scheme helped the development of meteorology in India because one of the tasks assigned to sanitary inspectors was to record daily meteorological observations.

There was a severe famine in Bengal and Orissa in 1866. The commission

which inquired into this famine recommended among other things the study of the trend of rainfall. The importance of monsoon rains to India was realized. It was recognized fairly early that deviations from the normal pattern of monsoon rain could be one of three types: (a) a late onset or an early withdrawal of rain over large parts of the country; (b) a large decrease in the quantum of monsoon rain for the season as a whole; and (c) periods of heavy rain or lean rainfall within the monsoon season. Such deviations were associated with floods and droughts in one or several parts of the country. Thus, as a consequence of these catastrophes and the inquiries which followed them there grew up within the country the nucleus of a meteorological data-gathering organization leading to the growth of a full-fledged department in the years that followed.

INDIA METEOROLOGICAL DEPARTMENT (IMD)

The India Meteorological Department (IMD) with jurisdiction over the entire country was formally set up in 1875. H. F. Blanford, who later became a fellow of the Royal Society of England, was made the first Imperial Meteorological Reporter to the Government of India with its headquarters in Calcutta. He was assisted by four provincial meteorological reporters. They were responsible for the Provinces of Bengal, Punjab, Madras, and the United Provinces (now Uttar Pradesh), and their central offices were located in Calcutta, Lahore, Madras, and Allahabad respectively. A year later another Imperial Reporter was appointed for Bombay Presidency and western India.

The first steps towards uniformity in meteorological equipment and instruments were taken at this time. A central observatory was organized in Calcutta in the beginning of 1877. Arrangements were made here to compare the performance of instruments used by the different Indian observatories against standard instruments at Calcutta.

An interesting item of work taken over by the new organization from the Survey of India was a time-service which enabled mariners to standardize their chronometers. In those early days this was achieved by dropping at fixed times a metallic ball from a tower or a suitable location near the port so that it was visible to mariners.

An Indian daily weather report first appeared in 1878. It was published at Simla from the beginning of the monsoon season and provided a summary of the weather prevailing over different parts of the country. The first weather chart of India made its appearance on 1 September 1887. It depicted the pattern of pressure, the direction of winds over India at 10 a.m., and the rainfall recorded in the previous twenty-four hours.

Among the first Indian employees of IMD were Phanindra Mohan Basu and Lala Hem Raj who was the first Indian to become Imperial Meteorologist.

Blanford retired in 1889. In his paper on Indian rainfall published in 1909 and regarded as a classic, Blanford repeatedly stressed its seasonal character. Over seventy per cent of the country's rainfall was recorded in a hundred-day period from the beginning of June to the middle of September each year, and any departure from the normal expectation of rainfall led to periods of extreme stress. Blanford was succeeded by Sir John Eliot, whose designation was changed from Imperial Reporter to Director-General of Observatories. At this time the word 'observatories' referred to not only meteorological observatories but also the observatories for astronomy and geomagnetism. Eliot's tenure as Director-General was marked by a number of events of far-reaching consequence. Until 1899 the Meteorological Department had no building of its own. But in that year a building was constructed in the present compound of the observatory at Alipore. This building is still used as the office of the Regional Meteorological Centre in Calcutta (Plate III).

Eliot retired towards the end of 1903. He was succeeded by Sir Gilbert Walker who gave up a Chair of Mathematical Physics at Trinity College, Cambridge, to become the Director-General of the Meteorological Department of India. In the early part of his tenure, in 1905, the headquarters of the Department was moved from Calcutta to Simla. Upper Air Observatories which utilized kites to lift meteorological instruments with the help of a winch were started at this time in Karachi.

Early Years of the Twentieth Century: Three very capable scientists—G. C. Simpson, Sir Gilbert Walker, and J. H. Field—came to India from the United Kingdom in the early years of the twentieth century. Simpson joined IMD in 1906 but left India in 1910 to join an expedition to the South Pole. He returned for another brief spell in 1912. He rose to be a prominent figure in the field of world meteorology, his contributions ranging from the Indian monsoon to atmospheric electricity and the physics of the upper atmosphere. A paper on the Indian monsoon was published by him in 1921 which stressed, perhaps for the first time, the importance of mountain barriers on monsoon rain, especially in north-east India.

Walker was the Director-General of Observatories for twenty-one years from 1903 to 1924. He was one of the first to realize the importance of long-range forecasts for monsoon rains. In a series of meteorological memoirs he published methods for forecasting the total rainfall during the hundred-day monsoon period from the beginning of June to the middle of September. His technique was to search for associations, in a statistical sense, between monsoon rain and other meteorological events in different parts of the world. Earlier, he had felt that the energy from the sun must have an important role to play in generating monsoon rain. That is why in the early part of his work we find a wealth of statistical correlations between sunspots and several meteoro-

logical variables such as atmospheric pressure, temperature, and rainfall. He suggested that fluctuations in solar energy tended to cause large-scale oscillations in atmospheric pressure. He found, for example, that whenever the pressure was high over the South Pacific Ocean, there was a tendency for the pressure to be low over the Indian Ocean. This is now known as the southern oscillation. Another finding of Walker was that a departure from the normal date of onset of rains over Abyssinia was reflected in a similar deviation in the onset of monsoon rains over India.

As years went by, meteorologists found that the correlations suggested by Walker were not as strong as was initially believed. The correlation coefficients varied widely with the passage of time. Some of the correlations even changed their sign. One of the main difficulties with his technique was the absence of any means of anticipating when and how the influence of a predictor would change with time.

In the last few years of his tenure Walker recruited four young scientists, all of whom have left their imprint on the chronicles of Indian meteorology. First, there was G. Chatterji from Presidency College, Calcutta, who was placed in charge of an Upper Air Observatory in Agra. In later years he did pioneering work in developing the first Indian radiosonde, a balloon-borne equipment for probing the atmosphere. After Chatterji, S. K. Banerji, a young Professor of Mathematics in the University of Calcutta, was recruited in April 1922. He later became the first Indian Director-General of Observatories after World War II. He was a distinguished scientist whose work on the association of microseisms (earth tremors) and the propagation of monsoon disturbances over the sea was widely recognized as original and well-reasoned. He was an applied mathematician who tried to work out mathematically the deviation of an air current as it struck a mountain barrier. In this he was ahead of his time, because research on this topic is still in progress in many parts of the world. V. V. Sohoni (March 1922) and B. N. Banerji (January 1923) were the two other Indians recruited by Walker. Sohoni later rose to become the head of the Indian Meteorological Service after Banerji.

At this time three part-time posts of meteorologists at Calcutta, Madras, and Bombay were filled respectively by P. C. Mahalanobis, S. R. Savoor, and V. D. Iyer. They were the first Indians to hold these posts. Mahalanobis subsequently won recognition as a distinguished statistician, but he retained his love for meteorology even after he had left the Meteorological Department. Towards the beginning of the Second World War he studied the rainfall, run-off, and other meteorological features of the river basins of Orissa. His work led to a prediction formula for the level of the river Mahanadi at a place named Naraj. This is described by him in a classic paper entitled 'Rain Storms and River Floods in Orissa' (1940).

In December 1924 Walker retired and was succeeded by Field. Two important developments took place during Field's brief term. The first was the transfer of the Meteorological Department's headquarters from Simla to Poona (now Pune) in 1928 (Plate IV). The second was the recruitment in 1925 of two more Indian scientists, K. R. Ramanathan and S. N. Sen, who subsequently had distinguished careers in the Department. Ramanathan won many laurels for India during his tenure of office as well as after his retirement. The International Union of Geodesy and Geophysics (IUGG) elected him as its President just after World War II. He was the first Indian scientist to be elected to this high office. The World Meteorological Organization (WMO) awarded him after his retirement one of its prestigious prizes—named after its predecessor, the International Meteorological Organization (IMO). Ramanathan's best contributions relate to the study of ozone in the atmosphere. He is currently Professor Emeritus at the Physical Research Laboratory in Ahmedabad where he is active with his students in the study of aeronomy, the science of the upper atmosphere. Sen joined the Meteorological Department after he had been several years with the British Meteorological Service. He had an innovative mind and tried to introduce new concepts of weather analysis for the tropics. He was perhaps the first to lay stress on the importance of wind data for identifying atmospheric vortices in the tropics. In 1928 he led an expedition to study the nor'westers of Bengal. This was one of the field experiments organized by IMD.

Field was succeeded by Charles Normand in 1928. Normand remained in India as the Director-General of Observatories for sixteen years. He is remembered for his research on the thermodynamics of the atmosphere. He derived three propositions which are now known as Normand's theorems. They enable a meteorologist to know the invariant properties of the wet bulb temperature in the atmosphere.

Normand was succeeded in 1944 by S. K. Banerji who did much to lay the foundations of modern meteorology in India. The immediate post-war period was given to reorganizing the Meteorological Department under new administrative procedures. In this Banerji was eminently successful. He expanded the network of upper air stations over India, which became an asset for weather-forecasting in the tropics. He started a quarterly, *Indian Journal of Meteorology and Geophysics*, which later became a useful journal for tropical meteorology. His contributions led to his election in 1948 as President of the Regional Commission for Asia of the International Meteorological Organization (IMO). Later, he was made an honorary fellow of the Royal Meteorological Society.

Meteorological Instruments and Observations: Soon after IMD was formally established in 1875 there was a rapid increase in the number of organizations

for collecting data over different parts of the country. By 1877 there were seventy-seven observatories in the country. By the end of the nineteenth century the number had gone up to 200. This progress was maintained over the years. In the meantime, progress in the standardization and design of instruments for recording surface observations continued unabated. In 1871 arrangements were made for keeping continuous records of temperature, humidity, pressure, surface winds, and rainfall at Bombay, Calcutta, and Madras. A seismograph was also installed at Alipore in Calcutta towards the end of the nineteenth century.

Upper Air Observations : The earliest upper air observations in India were made in January 1843 by Buist, who was in charge of the observatory in Bombay. He sent up a balloon from Byculla, a suburb of Bombay, to study the movement of upper air currents. The balloon followed the direction of a sea breeze up to about 500 ft. Similar experiments were organized at Calcutta soon thereafter. But systematic upper air observations were started only in 1905. An upper air observatory was set up at Agra in 1914 (Plate V). A meteorograph (Plate VII) was launched on specially designed kites (Plate VI). The temperature and humidity were recorded on a silver plate which was retrieved after lowering the kite back to the ground. But these kites only reached a height of 2 km. and each flight lasted between four and five hours. The kite meteorograph was heavy and expensive and took too long to probe the atmosphere.

G. Chatterji was the earliest to begin work on a radiosonde. His work finally led to the development of the Indian radiosonde by L. S. Mathur in Delhi and S. P. Venkateswaran in Pune. This was a balloon-borne instrument package which recorded the pressure, temperature, and humidity during its ascent into the atmosphere. The meteorological sensors of the Indian radiosonde were (i) an evacuated metallic capsule to measure the atmospheric pressure and (ii) bimetal strips to measure the dry and wet bulb temperatures. The sensors came in contact with a radio transmitter, in turn, by a shaft which was rotated either by a clockwork mechanism, or by a rotating fan. The observations from the radiosonde were communicated to a receiver on the ground.

During World War II, it was soon realized that data on upper winds were required at much greater heights than was possible by optical methods of tracking a balloon, because the balloon soon got lost in clouds. It was not possible to track a balloon, for example, during the monsoon when the skies were largely overcast. To overcome this difficulty attempts were made to track balloons with war-surplus anti-aircraft radars. These experiments led ultimately to the development of radio-theodolites in the Meteorological Department.

Calibration of Instruments: In the early history of IMD the Alipore observatory was responsible for the calibration and maintenance of instruments. In 1928 an instruments division was formed in Pune which gradually took over all work related to meteorological instruments. J. M. Sil was the earliest to develop this division. He had been trained as an engineer before he joined the Meteorological Department, and he spent a number of years trying to improve devices for measuring rainfall and visibility. By 1947 the Department had two workshops, one at Delhi and the other at Pune. The workshop at Pune was entrusted with the development of instruments needed for recording observations at the earth's surface, while the Delhi workshop concentrated on instruments required for probing the upper atmosphere. At present the Delhi and Pune workshops manufacture almost all the meteorological instruments required by the Meteorological Department. The Department has also set up a factory in Agra for manufacturing hydrogen. This is required for balloons to carry instruments into the upper atmosphere.

Along with the development of standard meteorological instruments, progress was made in designing instruments for special observations. The instrument for the measurement of ozone is an example. Ozone is one of the rare gases in the atmosphere which absorbs the ultra-violet rays of sunlight. But for the existence of ozone, the increase in ultra-violet radiation reaching the earth could lead to harmful effects such as bone cancer. Its measurements are also useful for tracing the movement of pressure systems in the stratosphere. A spectrophotometer for measuring ozone was developed by Dobson in Oxford during the early years of World War II. This spectrophotometer was introduced in India by K. R. Ramanathan. He and his associates studied the distribution of atmospheric ozone over India.

Forecasts and Weather Services: The seasonal character of Indian rainfall and its impact on the predominantly agricultural economy of the country necessitated accurate forecasting of weather conditions. This need was felt all the more in view of the devastation caused by tropical cyclones which hit the eastern coast of India year after year. These and other reasons led to the growth of a regular weather information service of the Meteorological Department. A later development which caused further progress in the forecasting service was the growth of commercial aviation, particularly after World War II. Initially, the forecasting activity was largely confined to the collection of data and improvement of operational techniques. But, it was soon realized that, mere collection of data was of no use unless meaningful inferences could be drawn. Another difficulty was that collection of data over a large country like India required an extensive network of meteorological stations involving large resources in both manpower and money. The fact that in spite of such difficulties the Department was able to expand its weather services is a measure

of the growing importance of meteorology and its appreciation by the Government agencies and administrators.

It is interesting here to note how small beginnings in data collection laid the foundations of a medium-sized forecasting industry by the end of World War II. Storm warning services were first introduced in 1861 at the Calcutta port. The system was gradually extended to the west coast by 1880. In the early days warnings were communicated to the port authorities by weather telegrams. The ships at sea were warned about an approaching storm during daytime by suspending a large cone at the port and at night by placing three lamps in a triangular formation below the cone. By 1886 the storm warning system had been extended to cover all ports in India and Burma. Around 1900, a system of eleven different signals was adopted. These signals were graded according to the severity of the expected tropical storm. This system is still in vogue with minor modifications. A full-fledged cyclone warning centre was established in Calcutta in 1921, and a similar centre was set up in Bombay for the Arabian Sea some years later.

The collection of meteorological data from ships' log-books appears to have commenced in 1881. At the turn of the century, such data were utilized by the Department to prepare charts of the mean pressure, the wind-speed, and surface ocean currents. This system was gradually expanded in the years preceding World War II. But during the war years shipping dwindled and meteorologists in India and Burma had to depend for data on aerial surveillance reports from reconnaissance aircraft belonging to the Royal Air Force (RAF) and the United States Air Force (USAF).

Telecommunication: Progress in the collection of data for weather forecasts synchronized with the development of telecommunication in India. In 1877 weather data were collected from the different observatories on post cards. Records indicate that such data were received at Calcutta ten or fifteen days after the time of observation. Following a severe drought during 1876-77, the reception of weather data by telegrams was introduced in 1878. The data were transmitted in the form of special coded messages for reasons of economy. Improvements in telegraphic services enabled the Department to begin the publication of a daily weather report on something like real time from the second half of 1878. The first daily weather reports were published from Calcutta, but later the work was entrusted to the main meteorological centre at Simla. A weather chart was introduced along with the daily weather report from the beginning of September 1887. The weather charts showed the distribution of pressure, and the direction of winds at 10 a.m. of the relevant day, along with the rainfall recorded in the earlier 24 hours. After the headquarters of the Department were moved to Pune, an Indian daily weather report covering the whole country was prepared and issued from Pune.

But after the end of the war in 1945, regional daily weather reports were also commenced from the five regional centres of the Department. These centres were located at Calcutta, Bombay, Delhi, Madras, and Nagpur. In subsequent years, a farmers' weather bulletin was also appended to the regional daily weather reports.

Aviation Forecast: IMD was not seriously concerned with aviation in its early years because commercial flights did not exist then. The first aviation forecasts were probably prepared in 1921 at Simla to assist the Royal Air Force in its operations over Waziristan. To meet the requirements for upper wind data for such flights, two upper air observatories were set up—one at Agra in 1913 and another at Lahore in 1918. With the help of these observatories a general forecast for north-west India was communicated daily by telegram to the different centres of the Royal Air Force between 1921 and 1924. Forecasting offices were set up at Peshawar and Quetta in 1925, again for the benefit of the Royal Air Force operations. This forecasting service was augmented by another office at Karachi in 1926 for commercial flights to the Middle East. An observation mast was built at Karachi in 1927-28 to observe the flight of an airship R-101. This attracted much public interest then, but unfortunately the airship met a tragic end over France and never reached India.

An air mail service was started in 1929. A forecasting office was consequently set up at Delhi for co-ordinating the warning communications of adverse weather conditions for aircraft. In 1929 the Meteorological Department provided forecasts for special test flights of the Southampton Flying Boats from Singapore to Calcutta. Within a year this was extended to Rangoon and Victoria Point in Burma.

Aviation meteorology came to its own during World War II when numerous airfields were opened over many parts of India and Burma. A principal forecasting centre was set up in Bangalore in 1942, and by 1944 twenty-seven forecasting centres had been established in India. With the development of more sophisticated aircraft it was realized that a larger number of radiosonde stations would be needed. These stations were run largely with the help of Indian personnel.

SOLAR PHYSICS

One of the attractive features of the history of meteorology in India is the emphasis it has placed on solar physics and astronomy. A solar physics observatory was set up at Kodaikanal in 1899. About a year before this observatory was formally commissioned, Sir Norman Lockyer, then Astronomer Royal, had come to India to observe the total solar eclipse of 22 January 1898 visible over Maharashtra and central India. It was largely his enthusiasm that led

to the establishment of the Kodaikanal observatory. Its first director was Michie Smith (1899-1911), who was succeeded by J. Evershed (1911-22). Thereafter T. Royds (1922-37) and A. L. Narayan (1937-46) were the directors of this observatory. Evershed, a distinguished astronomer whose investigations on solar prominences were largely conducted in India, was chiefly responsible for organizing observations of the total solar eclipse of 1898. N. D. Nigamwalla also organized, entirely on his own, a team to study this eclipse. Although not formally associated with the Meteorological Department, Meghnad Saha contributed to the astronomical studies in this country through his explanation of the brightness of stars by thermal ionization. This was another noteworthy event for Indian astronomy in the early 1920s.

Narayan was succeeded in 1946 as the director of the Kodaikanal observatory by A. K. Das, who continued to guide the scientific work of this observatory until 1959. The international community of astrophysicists recently recognized Das's contributions by naming a lunar crater after him. He set up a 20-inch reflector telescope at Kodaikanal and was responsible for extending the work of the observatory to a number of fields ranging from stellar physics to cosmic radiation. Some of the data which he and his collaborators collected are recognized to be among the best in the tropics.

METEOROLOGY AND INDIAN AGRICULTURE

On the recommendation of the Royal Commission on Agriculture (1926) a separate division for agricultural meteorology was created in 1932 within the Meteorological Department. The first director of this new division was L.A. Ramdas, who with his associates prepared a crop-weather calendar for India. This calendar provided information on the meteorological conditions needed for different stages in the growth of a crop such as sowing, germination, transplanting and, finally, harvesting. The calendar covered all the major crops grown in the country. In 1945 arrangements were made for issuing farmers' bulletins from the Meteorological Department. These bulletins are broadcast even today by All India Radio. Ramdas and his associates initiated a number of other projects concerned with evaporation and the loss of moisture from the soil. These topics form the basis of specialized branch of meteorology known as micrometeorology.

CLIMATE AND CLIMATIC CHANGES

The data collected through meteorological observations since 1793 have been preserved at the headquarters of the Department in Pune where an archiving centre has grown up into a national data centre. Here research has been directed to the study of Indian climate and its vagaries. Part of this research relates to the growth of the Rajasthan desert. The history of this area may be

divided into four stages: (i) 8000 B.C.— the climate was moist, wet, and cool; (ii) 8000-3000 B.C.— a dry climate, but less arid than at present with evidence to suggest the beginning of agriculture; (iii) 3000-1700 B.C.—a period of higher rainfall; (iv) 1700-1500 B.C.— a period of dry conditions with evidence of fresh-water lakes drying up. From 2000 to 1700 B.C. the climate of the region was very favourable for human habitation. Historical evidence suggests a number of desiccated valleys and a system of rivers which once reached the sea as tributaries of the Indus. There were periods of good rainfall followed by years of dry or semi-arid conditions. After the last period (1700-1500 B.C.) very arid conditions prevailed over the area. It is not clear whether these fluctuations in the climate of Rajasthan were part of a world-wide climatic change or the result of human activities. There are records of similar climatic fluctuations in other parts of the world, and the question still remains unanswered.

Apart from the studies on climatic changes, research in the archiving centre at Pune was largely confined to the study of the upper atmosphere. Around 1930 K. R. Ramanathan published a map showing the distribution of upper atmosphere temperature over the northern hemisphere. The map attracted much interest because it revealed that the stratosphere over the tropics was at a much higher altitude than in the mid-latitudes. The tropopause over the equator, for example, was located at 16 km., while at 60°N it was near 10 km. This map was used as reference material for many years until more data became available with the help of sounding rockets and weather satellites.

SEISMOLOGY AND GEOPHYSICS

Studies on Indian earthquakes owe their origin to a suggestion by the Royal Society in 1877. In 1882 a sum of Rs 2,000 was allotted for providing a simple seismograph each at Silchar, Shillong, and Sibsagar in north-east India. Regular seismic observations appear to have started in 1897. At the turn of the century the network of seismological stations had been expanded to cover Calcutta, Bombay, Madras, and Simla. Two disastrous earthquakes—one in Bihar in 1934 and the other in Quetta (now in Pakistan) in 1935—led to further intensification of the study of earthquakes. The network of seismological stations, especially in north-east India, was further improved. A special officer, C. G. Pendse, was appointed towards the end of 1939 for carrying out seismological research. He published a series of theoretical papers on the response of seismographs. S. K. Banerji's findings on the association between microseisms and the propagation of monsoon depressions referred to earlier appeared at one stage to be a very promising approach for fixing the location of tropical cyclones and other meteorological disturbances while they were still at sea, inasmuch as ship data from oceanic regions were difficult to come by. Unfortunately, the seismographs available at that time did not have the required

degree of sensitivity, and there were other areas of uncertainty which prevented full utilization of this technique.

Geomagnetism: Work on geomagnetism also owes its origin to a recommendation by the Royal Society of England around 1840 although hourly magnetic observations were recorded at the observatory in Madras from 1822. In 1840-41 three geomagnetic observatories were started in India at Colaba, Trivandrum, and Simla. The observatory at Trivandrum was set up largely at the initiative of Rama Verma, Maharaja of Travancore. On the advice of J. Caldecott, commercial agent of the Travancore Government, the Maharaja sanctioned funds in 1836 for an observatory building. Caldecott continued to guide the work of the Trivandrum observatory until his death in December 1849.

After the early years the study of geomagnetism mostly centred round the observatory at Colaba. The British Government had originally decided to set up a magnetic observatory at Aden, which was in those days an important British naval station. But owing to technical difficulties, the equipment meant for Aden was transferred to Bombay where, at the suggestion of Col. Sykes, it was placed in charge of A. B. Orlebar, Professor of Astronomy in Elphinstone College. In 1865 Charles Chambers was appointed full-time Director of the observatory. He was succeeded in 1896 by N. A. F. Moos, first Indian Director of the Colaba observatory.

When electric tram service was introduced in the city of Bombay in 1900, it became necessary to transfer the geomagnetic work from Colaba to another site because of the harmful effects of electric currents on geomagnetic data. Accordingly, a new site was selected at Alibag, eighteen miles south-east of Bombay, and a new building was constructed there in 1903 entirely with non-magnetic material. The transfer of the magnetic observatory was completed in 1906. Moos published in 1910 a series of monographs on the magnetic data and instruments that were used at Colaba.

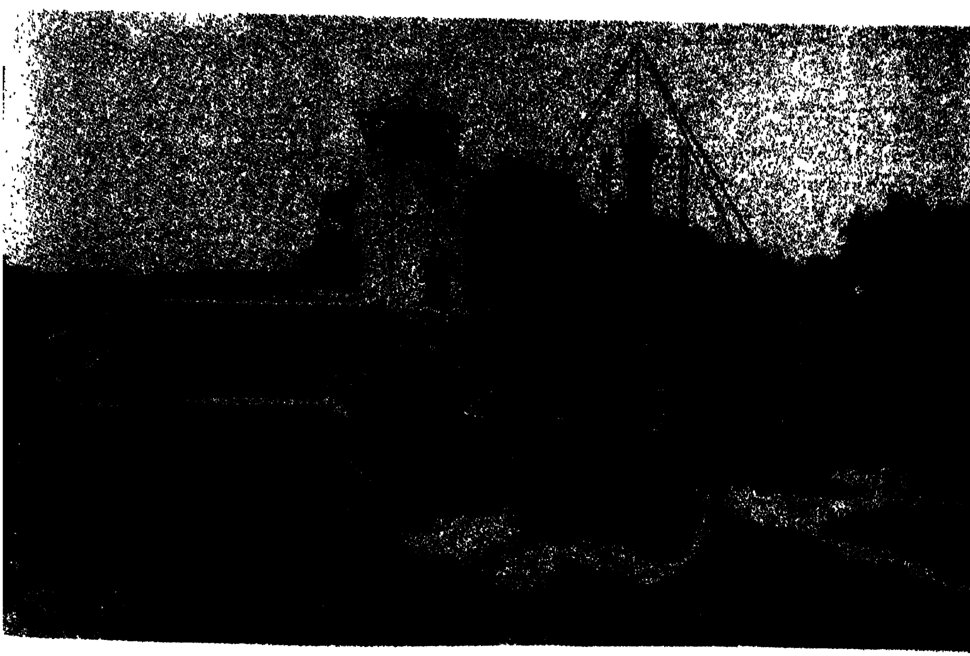
CONCLUSION

The India Meteorological Department (IMD) celebrated its centenary in 1975. During the hundred years, 1875-1975, IMD witnessed considerable changes in emphasis and organization. It should be remembered, however, that the foundations for these changes were laid by the scientists and pioneers who developed and sustained the Department during the first seventy years of its existence. There were periods of rapid expansion just as there were spells of comparatively slow growth. All this contributed to the stabilization of IMD as a national agency for providing efficient service in the field of meteorology. The Department now collects meteorological data from over 1,400 observatories of different types and processes them. In collaboration with the Indian Institute of Tropical Meteorology (IITM), Pune, IMD conducts fundamental

PLATE I

THE GRANITE PILLAR WHICH CARRIED WILLIAM PETRIE'S ORIGINAL TRANSIT INSTRUMENT—NOW PRESERVED AS A MONUMENT

PLATE II

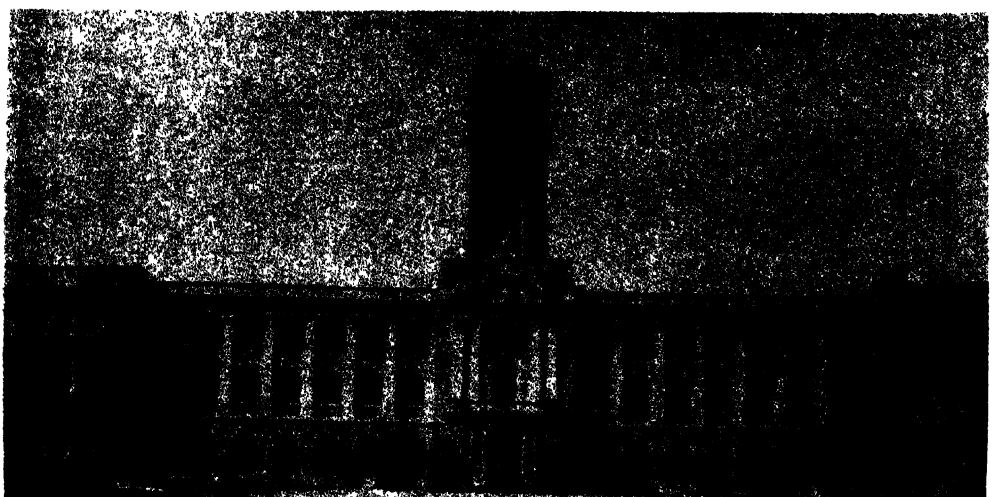


COLABA OBSERVATORY (1877)

PLATE III

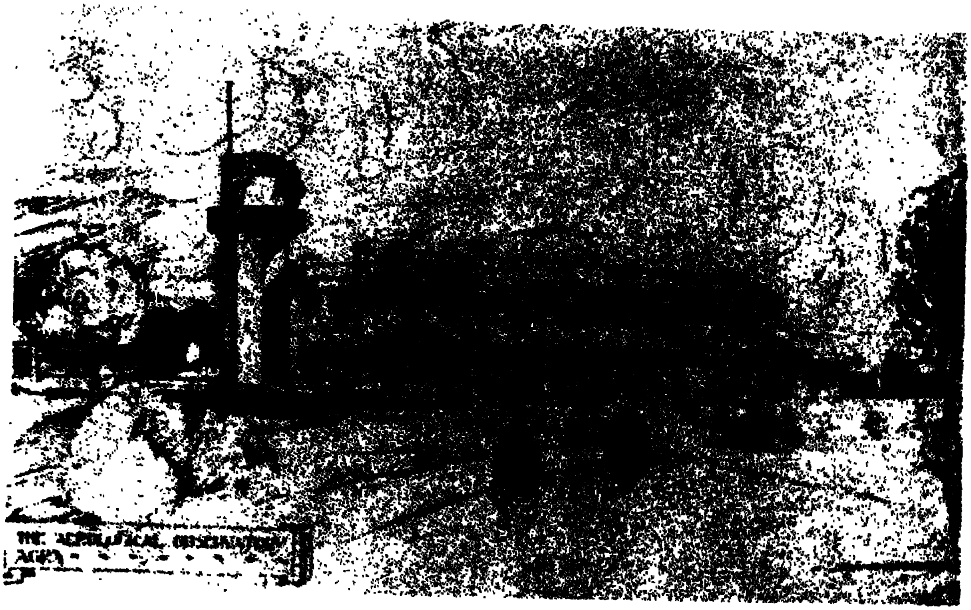
ALIPORE OBSERVATORY (1899)

PLATE IV



METEOROLOGICAL OFFICE, POONA (1928)

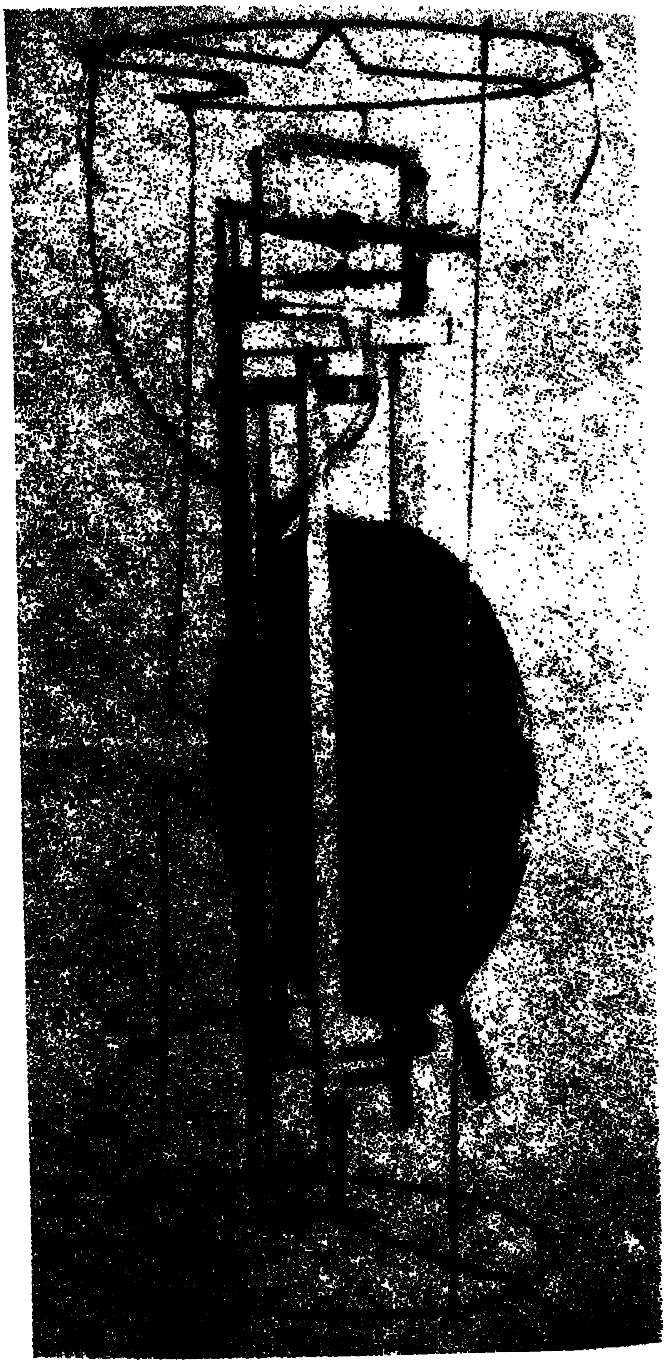
PLATE V



A SKETCH OF UPPER AIR OBSERVATORY AT AGRA (1914)

PLATE VI

PLATE VII



DINES METEOROGRAPH

and applied research in such subjects as weather forecasting, meteorological instrumentation, radar meteorology, seismology, agricultural meteorology, hydrometeorology, satellite meteorology, and air pollution. Among the universities and institutes at which meteorological research is now carried out are Banaras Hindu University; Andhra University; Cochin University; the Indian Institute of Technology, New Delhi; and the Indian Institute of Science, Bangalore.

IMD issues warnings against heavy rainfall, strong winds, and cyclonic weather for the benefit of the general public as well as a number of private and public organizations. It has floods meteorological offices functioning at Ahmedabad, Asansol, Bhuvaneswar, Gauhati, Hyderabad, Jalpaiguri, and Patna to provide support to the flood forecasting organizations of the Central Water Commission. Cyclone warnings to ports and ships are issued by the Bombay, Calcutta, Visakhapatnam, Bhuvaneswar, and Madras offices. Weather satellite pictures are received through automatic picture transmission stations located at various places including Bombay, Calcutta, Madras, and Visakhapatnam. A cyclone warning and research centre at Madras investigates problems relating to tropical cyclones.

Three earlier constituents of IMD, viz. the Indian Institute of Astrophysics (IIA), Bangalore; the Indian Institute of Geomagnetism (IIG), Bombay; and IITM, have been functioning as autonomous institutes since 1971. While IIA conducts research in such areas of science as solar and stellar physics, radio astronomy, and cosmic radiation, IIG records magnetic observations and directs research in geomagnetism. An important work IITM concerns itself with relates to making experiments (cloud seeding experiments) for artificial production of rain.

The points mentioned above give an idea of the kind of studies and research being conducted in this country now in meteorology and subjects closely related to it. They also indicate the position India has attained in its weather services—a position which may not compare unfavourably with that held in this sphere by some of the technologically-advanced countries of the world.

AGRICULTURE AND ANIMAL HUSBANDRY

AGRICULTURE dominates rural life in India, and nothing represents this country more truthfully than its villages. Some of the agrarian features of an average Indian village at the beginning of the nineteenth century were as follows: water supply, where available, through tanks for drinking and irrigation; fuel from dung cakes, wastes, and forests close to the village; seeds from surplus production or grain shop; cattle breeding by sire freely available; hereditary occupations; urge for self-sufficiency in comparatively remote villages; minimum area under cultivation owing to lack of security, incentive, outside market, communication, and trade channel; meagre storage against drought, flood, and damage by locusts because of small surplus production and low capacity to hold stock. The major developments in this agrarian set-up in India since the beginning of the nineteenth century have, for convenience of discussion, been treated under the following periods: 1800-1858; 1859-1879; 1880-1904; 1905-1919; 1920-1928; 1929-1947, and the post-independence years.

1800 - 1858

Towards the close of the eighteenth century two events pertaining to agricultural development stood out prominently. In 1788 the Court of Directors of the East India Company requested its representatives in India to encourage the production and improvement of cotton. Accordingly, the East India Company brought in 1793 several American cotton experts, three of whom were sent to Bombay. The second major event was the Permanent Settlement of 1793 which converted revenue farmers of Bengal into proprietors of land and introduced the zemindari system there. About the same time the ryotwari system became the recognized form of land tenure in Bombay and Madras. The East India Company actively encouraged brisk export trade which, together with the land tenure system, broke up the village community and shattered the dynamism of the rural economy. Agricultural development under the new land tenure system was an impossibility because the tiller of the soil had no right to the land he cultivated. After paying government revenue and interest to the ubiquitous money-lender, the cultivator could invest little for production purposes. In spite of increased demand for agricultural produce caused by export trade, agriculture and the agriculturist languished, while

the money-lender, the middleman, and the landlord prospered. Rural indebtedness rose to about nine billion rupees. Land laws undermined the influence of village communities and converted cultivated lands into a form of business investment.

Exotic Cotton: In the first half of the nineteenth century private associations with European membership sprang up with a view to introducing improved exotic varieties of cotton. The American Civil War (1861), which cut off all supplies of cotton from that country, provided an incentive to cotton production in India. A cotton commission was set up in 1866-67 in the Central Provinces (now Madhya Pradesh). Meanwhile, some experimental farms were established to try exotics. Improved varieties of potato, cinchona, and tea were also introduced. But all these trials without previous study failed to yield the desired results. Although not entirely altruistic in motive, genuine interest of the East India Company to improve Indian agriculture was expressed in the despatch of 19 July 1854 by the Court of Directors, which stressed that 'there was no single advantage that would be afforded to the vast rural population of India that would equal the introduction of an improved system of agriculture .

Sugar in Bengal: Bengal grew sugar-cane profusely and exported sugar as early as 1674 to Europe through the East India Company. The Bengal product was as good as that of the West Indies. But owing to high differential duty imposed on Bengal sugar in order to protect the West Indies industry, the former could not compete. For the purpose of developing export trade in sugar a factory was started in 1794 in Rangpur (now in Bangladesh), but it failed after running for only six years. In 1829 C. H. Blade established Dhoba Sugar Works near Kalna in the Burdwan district of Bengal. Several ventures by Europeans in 1840 to start sugar factories in Nadia and Jessore also failed.

Agri-Horticultural Society: The Agricultural Society of India was founded by William Carey in 1820. It was renamed Agri-Horticultural Society of India in 1826. The February 1840 issue of the proceedings of the Society recorded the production of cotton in Tippera Hills to the extent of 100,000 maunds (3,750 tonnes) and of superior quality sea island cotton on the sandy soil at Kanpur. It also referred to the feasibility of hemp cultivation for making rope and sackcloth. Hemp was exported to England. Forty to fifty different kinds of plants were studied by Roxburgh for selecting the one most suitable for cordage and fibre. Of these, hemp and jute received considerable attention. The proceedings published progress reports of tea cultivation in Assam and the prospects of cotton cultivation in Bengal. Also published was an account of attempts of an Italian silk expert, F. Lotteri of Bergino, to improve Assam silk. He did produce an improved variety of silk, but the cost was about six times the local product.

Irrigation: The restoration of Firoz Shah's canal on the west bank of Jamuna commenced during the administration of the Marquis of Hastings (1814-23). The canal was so efficiently laid out that it was capable of irrigating 500,000 acres in 1870. Because of faulty drainage, waterlogging was noticed as early as in 1823. Drainage rightly considered the only answer, baffled engineers for nearly a century. Investigation and development of canal irrigation started in 1836. The three following decades saw the completion of the big river diversion works, viz. Upper Ganga canal, Upper Bari Doab canal, and Krishna and Godavari delta systems. Some private companies, encouraged by profits from canal systems, started a few irrigation projects on a grandiose scale, but finally gave up the effort after making bits of waterways, of which the Midnapore canal, Orissa high-level canal, and Kurnool-Cuddapah canal are some examples. The recurrence of famine during the second half of the nineteenth century necessitated the development of irrigation to meet threats of crop failure.

Animal Husbandry: By far the largest and oldest animal farm in British India, a camel-breeding farm covering an area of 42,000 acres, was established at Hissar in 1809 by the Punjab Government. Cattle and horse breeding were added there in 1815. Mysore was famous quite early for improved cattle-breeding for draught and milk. The local breeds were deemed very efficient for use by the military authorities who considered them as perfect. Captain Harvey's memorandum dated 1813 mentions the practice of castration by Mysore cattle breeders. Cross-breeding of sheep was attempted as early as 1826 when the Bengal Government acquired a flock of country ewes and imported forty merino rams and ewes for the purpose. Cross-breeding carried out in the United Provinces (now Uttar Pradesh) at about the same time failed owing to the fact that the cross-bred animals could not stand the hot climate of the plains. Over one hundred selected sheep of different breeds were imported from England and a farm was opened in 1835 near Ahmednagar in Gujarat for cross-breeding. After some initial success the experiments were abandoned. Horse-breeding, which started in the Hissar farm in 1815, continued up to 1850 when the farm concentrated on raising artillery and ordnance bullocks.

1859-1879

Expanding Export: Expanding export trade acted as an incentive to agricultural production during the period under review. The opening of the Suez Canal in 1869, with the resultant reduction of freight charges to almost half, provided further inducement. In the meantime, the Civil War in North America disrupted cotton supply to England, which turned towards India for this commodity. The value of cotton export rose from Rs 56,000,000 in

1859-60 to Rs 375,000,000 in 1864-65. Similar growth in exports was recorded in rice, wheat, and other foodgrains. Other exports included opium, indigo, and hides and skins, the values of which increased progressively from Rs 289 million in 1859-60 to Rs 692 million in 1879-80 and to Rs 1,657 million in 1906-07. As a result, agricultural produce was gradually commercialized. The process was accelerated by the development of the railways from 460 km. to 49,200 km. during the fifty years from 1857.

Although foreign demand for cotton fell to some extent after the American Civil War, internal demand increased because of the introduction of modern machinery for spinning and weaving for producing more sophisticated types of cotton textiles. Yet, neither productivity nor the area under cultivation increased as expected because of lack of resources and organization. The increased market demand, however, led to the replacement of foodgrains by commercial crops which had a good export market. The cultivation of commercial crops was regionalized according to favourable climatological conditions. Thus cotton was limited to the Deccan districts and the canal areas of the Punjab; jute and indigo to Bengal; tea to Assam; and opium to Bihar. Wheat and cotton were restricted to the canal areas in the Punjab where irrigation was specifically developed for increased production of these two crops. This type of regional specialization broke up the traditional system in which a region or a village tended to be self-sufficient. A region devoted to a cash crop was empowered to import foodgrains and other necessities. Often the system of storing for lean years was out of fashion. On the other hand, even the village economy became exposed to world fluctuations in price so that the farmer's decision was influenced more by outside market forces than by internal demands. It was clearly mentioned in the evidence before the Famine Enquiry Commission of 1880 in Bengal and Orissa that the best lands were in the possession of planters for the cultivation of indigo, and that since the planters increased the area under indigo the area under rice fell. A similar situation was noticed in the North-Western Provinces (now Uttar Pradesh) where cotton replaced foodgrains, and in Rajputana where poppy cultivation supported by the Government replaced food crops. This trend finds support from the observation that the ratio of non-food to food crops went on increasing steadily in the course of the subsequent fifty years.

Indigo and Cinchona: Indigo dye was known to the Romans and Greeks (Gr. *indikon*). European travellers of the late eighteenth century spoke of indigo being cultivated in West and South India. There was evidence of the dye being processed in West India and shipped from Surat. It was carried by the Portuguese in Lisbon to dyers in Holland, but they soon procured supplies from the Dutch East India Company. When the English East India Company started exporting indigo from Surat to England the trade began to flourish. But soon

it languished due to competition from America-grown indigo. The market revived when the Americans took to cultivating other crops like sugar, coffee, etc. in place of indigo. Indigo cultivation in India thereby received a stimulus and the East India Company organized experiments in indigo cultivation in Bengal. About forty different varieties of *Indigofera* were cultivated in India out of which *I. sumatrana* was most popular in Bengal. In 1862 cinchona plantations were started in Darjeeling and the Nilgiri Hills with seeds introduced from South America by Clements Markham. Several species were cultivated of which the most important were *C. legariana* in Darjeeling and *C. officinalis* in the Nilgiris.

Some attempts at agricultural improvement during this period failed due to lack of experience. For instance, in 1862 an agricultural society set up at Nagpur began a survey of cotton tracts. The Cotton Commissioner of the Central Provinces and Berar tried to import exotic varieties and cultivate them in new tracts without previous studies. The effort proved abortive. A cotton seed farm set up at Nagpur also proved unsuccessful. The same story is repeated in Madras in regard to agricultural implements. Without making any previous study and experiment, the Madras Government imported from England improved agricultural implements like the steam plough, steam harrow and cultivator, threshing machine, drill, horse-hoe, winnower, chaff-cutter, and waterlift. The working of these machines was demonstrated on a 350-acre farm at Saidapet in Madras in 1864. But the experiments turned out to be a failure and were abandoned. These failures occurred because the men in charge had hardly any knowledge of agriculture, far less of Indian agriculture.

In 1865-66 there occurred a famine which affected large areas of Bengal, Orissa, Bihar, and Madras. The Famine Commission of 1866 recommended the establishment of a special department of agriculture but the proposal was considered premature. It was revived three years later in 1869 at the instance of the cotton trade which wielded considerable influence on the shaping of agricultural policy of the Indian Government. In fact, it was the Manchester Cotton Supply Association which suggested the creation of a separate department of agriculture in each Province for improvement of cotton. Lord Mayo, who strongly believed that the recurrence of famine could be stopped only by improving agriculture on a scientific basis, took personal initiative in the matter and, in his memorandum of 6 April 1870 to the Secretary of State for India, recommended the establishment of a department of agriculture and commerce. The recommendation stressed that 'of all branches of Indian industry, agriculture, which constitutes the occupation of the great mass of the people, is by far the most important'. The supply of food, it was noted, was an important consideration as shown by recurrence of famines. 'For many generations to

come,' the recommendation added, 'the progress of India in wealth and in civilization must be directly dependent on her progress in agriculture' and 'agricultural products must long continue to constitute the most important part of our exports'. Further, 'it could not be denied', the recommendation ran, 'that Indian agriculture was in a primitive and backward condition and that . . . the Government had not done for its improvement all that it might have done'. Concluding, the recommendation added: 'We cannot doubt that when the light of science has been properly brought to bear upon Indian agricultural experience, the results will be as great as they have been in Europe.' It must be admitted that the assessment was absolutely correct.

Department of Agriculture: Ultimately, the Department of Revenue, Commerce and Agriculture was established in June 1871. It functioned till 1879 but was reconstituted in 1881 on the recommendation of the Famine Commission of 1880. The only work of importance the department could do was to evolve systems for collection of agricultural statistics and other data. The next few years saw the establishment in some of the Provinces of model farms for agricultural trials and experiments. The North-Western Provinces were the first to set up a department of agriculture in 1875 through the influence of the Governor, Sir John Strachey, who was a member of Lord Mayo's Government. Scientific agriculture was the main objective, special attention being paid to improvement of sericulture, indigenous fibres, and fine-grade tobacco. A milk farm in Dehra Dun, a tobacco farm at Ghazipur, and a fruit farm in the Kumaun Hills were set up as model farms. Seven such farms were also set up in different parts of Bengal as early as in 1871, but they disappeared during the famine of 1873-74.

Agricultural Education: A college of agriculture was established in Madras in 1876. Agricultural education was also started quite early in Bombay. To train students in scientific agriculture, a class in agriculture was opened in 1879 at the College of Science, Poona (now Pune). Writing in 1875, P. Dods, Inspector-General of Education of the Central Provinces, emphasized the need for imparting agricultural education to such civilian officers as were in charge of agriculture because they had little knowledge of the subject.

Cattle Diseases and Dairy Farm: Lord Mayo, who took great interest in the eradication of cattle diseases, set up a commission in 1868 to report on cattle diseases and the measures necessary for their prevention and cure. The commission recommended the establishment of a civil veterinary department, but not until 1891 was this recommendation implemented. Organized dairying in India owes its origin to the establishment of large-scale dairy farms by the military authorities at Allahabad in 1871. Butter and cream, however, were not popular. They constituted only five per cent of the milk produced whereas

ghee, because of its keeping quality and handling convenience, accounted for seventy-five per cent of the milk utilized.

1880-1904

Famine Commission: Almost as a ritual, every famine in India was followed by a commission. The reports of some of these commissions, based almost always on serious studies of facts and figures and discussion with experts, contained recommendations of far-reaching consequences, particularly in respect of agriculture. The report of the Indian Famine Commission and Famine Relief, 1880, with R. Strachey as president, made a thorough analysis of the frequency of famines and their severity, and concluded that the Government should be prepared for two famines of some degree of intensity in nine years and great famines at intervals of twelve years. It observed that the danger of extreme famines in any one Province or locality was once in fifty years, though drought might be reckoned once in eleven or twelve years. Seasons of drought, it found, did not simultaneously visit northern and southern India, but a bad year in the North might immediately follow a bad year in the South. The Commission recommended the preparation of a famine code laying down the principles of famine relief and discussed the necessity of a separate department to deal with famines, although the duties of the department of agriculture ought to cover famine relief. With regard to agriculture, the Commission recommended, among other things, (1) expansion of irrigation and railways; (2) revival of the department of agriculture at the Centre and in the Provincial Governments with the responsibility of (i) collecting information of past famines, (ii) undertaking definite and permanent charge of the administration of famine relief, and (iii) collecting facts in normal times in respect of the agricultural community and agricultural produce; and (3) liberal grant of loans to farmers on easy terms and on the security of land. The Commission fully recognized the need for bringing science and technology to bear upon agriculture and of regularly collecting accurate agricultural statistics. The following observations of the Commission are quite relevant in this connection:

'Our report has clearly shown how greatly agriculture preponderates over all other interests and employments in which the people of India are engaged; how essential we think it that technical agricultural knowledge should be called in to enable the productive powers of the soil to be applied in the most effective manner, not merely to add to the wealth of the country, but to secure a food supply which shall keep pace with the increase of population; and how valuable in all departments of administration would be the acquisition by the executive officials of more accurate knowledge of the statistics of agriculture, of the

outturn of the harvests, and the relative produce of the crops from year to year....It is our hope that an agricultural department may be established in every Province.'

AGRICULTURE DEPARTMENTS IN PROVINCES

Bombay: In pursuance of the recommendations of the Famine Commission, a new secretariat was set up at the Centre in 1881, headed by Edward C. Buck. Following this move at the Centre, some of the Provinces also began to step up their activities in agriculture and allied fields. In 1880 a farm was attached to the College of Science, Pune, to impart practical lessons in agriculture. In Bombay a department of agriculture was formed in 1883 with E. C. Ozanne as Director. In 1890 J. Mollison was appointed Superintendent of Experimental Farms. Mollison later became Deputy Director of Agriculture, Bombay Presidency, and then Inspector-General of Agriculture of India. Bombay University was the first in India to give recognition to agriculture by initiating the award of a diploma in agriculture to those who passed a three-year course in the subject from the College of Science or Baroda College. But employment of the diploma-holders being uncertain, admission dwindled to nil in 1895. In 1899 the diploma was replaced by a certificate of licentiate in agriculture.

Madras: The administration of the College of Agriculture in Madras was transferred from the Board of Revenue to the Director of Public Instruction in 1884. Infestation of sugar-cane, groundnut, and pepper by diseases led to the appointment of an economic botanist in 1898. In 1901 experiments on disease-resistant cane started. Imported varieties of groundnut were tried, and a farm was started to study the disease-resistance of pepper. Two farms, one at Bellary and the other at Tinnevelly, were set up for study of cotton and a third for agave in Anantapur district. In 1904 a farm for exotic cotton was started at Hagari.

U.P.: In the United Provinces (now Uttar Pradesh), although the decision to set up a department of agriculture was taken as early as 1875, it was started in 1881 with the Kanpur farm as the nucleus. Arboriculture was under the charge of the Department of Agriculture which took up roadside planting of trees. Construction of wells also made a good start. Reclamation of arid lands as well as cattle and dairy development centred round Aligarh. The opening of the College of Agriculture in the 1890s was an important event. The college trained teachers and subordinate revenue officials in scientific agriculture. In 1901 a Deputy Director of Agriculture was added to cope with the heavy duties of the Director. In 1904 an economic botanist was appointed and new farms were opened.

Bengal: In Bengal (including Bihar and Orissa) a department of agriculture was set up in 1885. Farms were established at Dumraon, Burdwan, and

Sibpur in 1887-88. Five demonstration farms were set up in 1889-90 and a few more later on. A Deputy Director of Agriculture was appointed in 1904. Agricultural education began in 1895-96 when classes were opened at Sibpur.

Assam: A department of agriculture was nominally created in Assam in 1882, but its only function was to carry out crop-cutting experiments on rice, mustard, and sugar-cane. In 1885-86 the department began to work for improving the local breeds of cattle. Potato development in the Khasi Hills owed its origin to the experiments done there with exotic varieties. The only Government farm was a fruit farm set up in 1885.

Central Provinces: In the Central Provinces and Berar (now Madhya Pradesh) cotton cultivation initially met with little success. With the appointment of Bamfylde Fuller as Director of Agriculture in 1883 things took a turn for the better. The Nagpur farm, set up as a cotton seed farm, was located on a new site, and experiments of a practical nature were started. The scheme of work was overhauled with the advice of the agricultural chemist to the Government of India. A training class started in 1888-89 in Nagpur subsequently developed into a good training centre.

Punjab: In the Punjab a department of land records and agriculture was set up in 1880. Till 1901 only some disjointed experiments on exotic varieties of cotton, wheat, and maize were done. In 1901 a 56-acre farm was started at Lyallpur in the Chenab colony which was staffed by agricultural assistants trained at Kanpur. A Deputy Director of Agriculture and an economic botanist for work in the United Provinces and the Punjab were stationed at Saharanpur.

Indigo Cultivation: The period under consideration witnessed a substantial decline in the area under indigo cultivation. The total cultivated area during 1899-1900 was 2,000 sq. miles, which declined to 1,100 sq. miles in 1903-04. The numbers of factories and persons employed in 1901 were 923 and 173,000 respectively; but by 1903 they had fallen to 531 and 82,000 respectively. The bulk of superior quality indigo was exported. Exports showed an increase from 100,000 cwt. in 1876-77 to 170,000 cwt. in 1896-97, but a decline in 1903-04 to 60,000 cwt. This coincided with the first marketing of synthetic indigo which gave a set-back to indigo cultivation and the associated industry. In Bengal the industry was greatly helped by research work instituted by the Association of Planters. Some good work was done on the chemistry and bacteriology of indigo.

Voelcker Report: The Department of Agriculture at the Centre, reconstituted in 1881 as a result of the recommendations of the Famine Commission, 1880, appointed J. A. Voelcker as agricultural chemist in 1889. He submitted a report in 1893 which attributed the backwardness of Indian agriculture to lack of knowledge, general as well as agricultural, and absence of an organiza-

tion at the district level to advise the farmer. Voelcker suggested, among other things, the appointment of chemists to study soil, water, fertilizer and manure, crops, and fodders for their quality; extension of irrigation; creation of fodder reserve; use of organic wastes, bones, lime, nitre, and cakes as sources of plant nutrients; cattle-breeding with improved stud bulls and investigations in cattle diseases; trial of new agricultural implements; experiments with new crops and methods of cultivation; production of improved seeds; study of industrial crops like sugar-cane, indigo, tea, coffee, and tobacco; advance of taccavi loans to farmers by the Agriculture Department; and spread of general and agricultural education. In his sympathy for the Indian cultivator, Voelcker wrote that at his best the Indian cultivator was quite as good as, and in some respects superior to, the British farmer, while at his worst it could only be said that this state was brought about largely by the absence of facilities for improvement.

Agricultural Research: Agricultural research received attention at a conference in 1890 when a decision was taken to appoint two scientists, one for research and the other for education. J. W. Leather, appointed as research scientist, began his work in 1892 at Pusa. S. H. Collins was principally concerned with teaching at Pune, Dehra Dun, and Saidapet and with questions relating to forest and agricultural chemistry. After the end of Leather's term, the post of agricultural chemist was abolished and that of Inspector-General of Agriculture created. In 1901 James W. Mollison was appointed the first Inspector-General of Agriculture. His duties were to make systematic studies of Indian agriculture and its remediable defects, to supervise and develop Provincial departments of agriculture, to introduce improved agricultural methods and new staples, and to direct the agricultural policy of the Government of India.

Earlier, in 1892, when Mollison had become Technical Deputy Director of Agriculture for Bombay Presidency, he had begun field experiments. The emphasis had hitherto been on chemical investigation of soils, plants, etc. In 1898 Barber was appointed to look for remedies of sugar-cane diseases. He began selecting disease-resistant varieties and produced some with remarkable success. This set the pace for plant-breeding research and lent support to the view that scientific research could lead to agricultural development. The importance of other branches of science was soon recognized, especially after the specific insistence of the Famine Enquiry Commission of 1901 that 'steady application to agricultural problems of expert research is the crying necessity of the time'. The appointments of E. J. Butler in 1901 as Imperial Mycologist (later designated as Imperial Cryptogamic Botanist) and Maxwell-Lefroy in 1903 as Imperial Entomologist followed in quick succession.

Agricultural Research Institute: On 4 June 1903 the Government of India addressed a despatch to the Secretary of State together with a scheme for the

establishment of an agricultural research institute at Pusa in the Darbhanga district of Bihar. The Institute got, through Lord Curzon, a handsome donation of £30,000 from Henry Phipps, a philanthropist from Chicago, U.S.A. With the establishment of the Institute at Pusa, the Central Agricultural Department staff, namely, the chemist, the mycologist, and the entomologist, were brought to Pusa where fully equipped laboratories, experimental farms, an agricultural college, a cattle farm, and students' training arrangements were set up. The functions of the Institute were (a) to run a farm which would serve as model for the Provincial departments; (b) to improve varieties of crops and to grow and distribute their seeds; (c) to test results of Provincial farms and to do such experiments as would require skill not available in the Provinces; and (d) to impart practical training to students at a higher level than what was available in the Provinces.

Irrigation: Following the recommendations of the Famine Commission of 1880 to advance taccavi loans for construction of wells and the initiative of the Provincial Governments for the development of irrigation, a spurt was noticed in this direction and several canals were opened between 1882 and 1885. Among these were: the Sirhind canal opened by Lord Ripon in 1882; the Sidhani, Lower Sohag and Para, and Chenab canals opened in 1884; and Swat canal in Peshawar opened in 1885. Because of good annual rainfall during 1880-95 the initial enthusiasm of the Government for the development of irrigation soon died down. But the two great famines of 1897-98 and 1899-1900 changed the Government attitude. The first Irrigation Commission in its report in 1903 suggested a number of measures to stimulate construction of private works and drew up a twenty-year plan envisaging an expenditure of Rs 440 million on public works to irrigate 2·6 million hectares. The Commission attached great importance to private irrigation works which accounted for 44 per cent of the irrigated area.

It also suggested liberalizing the terms of taccavi loans, reducing the rate of interest to 5 per cent per annum, sanctioning grants-in-aid to famine-affected areas for construction of wells, remitting loans where water was not struck, mapping tracts where well irrigation was feasible, and providing boring tools at nominal rates. Irrigation works began in the Punjab as early as 1887-88 with 2·5 million acres under command. In order to understand the movement of subsoil water, systematic data began to be collected by the Irrigation Research Institute, Lahore, in 1891. The Bari Doab canal had been opened in 1860-61 for irrigation. But waterlogging resulting from faulty alignment of the Jamuna canal necessitated its remodelling in 1870 and new branches were opened. As a result, its water irrigated 764,000 acres in 1897-98.

Animal Husbandry and Animal Health: Although a civil veterinary department had not yet come into existence, the question of animal health was receiving

the attention of the authorities during the last decade of the nineteenth century. The first Imperial Bacteriologist appointed to study animal disease began his researches at the Imperial Bacteriological Laboratory at Pune in 1890. Rinderpest was one of the serious scourages of cattle, particularly hill cattle. To facilitate research on rinderpest, the laboratory was transferred from Pune to Mukteswar in 1893 where the Imperial Veterinary Research Institute was set up. Anti-rinderpest serum began to be produced from 1901, and the Institute became ultimately self-supporting. The bulk production centre, however, was shifted later to Izatnagar where the main institute was located, Mukteswar being largely responsible for standardization and improved methods of treatment. Besides work on rinderpest, the Institute did a lot of research on other diseases like surra, anthrax, haemorrhagic septicaemia, and piroplasmosis. For supplying better fodder for animals in military service, grass farms were set up at Allahabad and Kanpur in 1882, where silage and hay-making were emphasized for better preservation of grasses. The Punjab Government farm at Hissar, used primarily for raising artillery and ordnance bullocks until 1899, was transferred to the civil veterinary department and eventually to the Punjab Government. The Hissar cattle represent a special strain of Haryana breed. The dual purpose cattle raised there were distributed to the neighbouring Provinces.

Agricultural Ledger: The first volume of the *Agricultural Ledger* was published in 1892 by the office of the Superintendent, Government Printing, Calcutta, and was edited by the Registrar of Economic Products to the Government of India. It appeared in the form of a series dealing with diverse agricultural and allied products, agricultural implements and machinery, crop diseases and pests, etc. Each series contained a wealth of information, including research findings and comprehensive articles on various aspects of agriculture. Occasionally there were special series. One such, for instance, treated of animal diseases; it gave an extensive summary of the Indian Cattle Plague Commission's report (1871), which studied historically from 1795 to 1871 the outbreaks of cattle diseases, their nature and category, mentioning preventive and curative measures relating to them. This appeared in the 1896 (No. 8) issue of the *Agricultural Ledger*.

1905-1919

Crop Research: The tempo of agricultural research increased during the period under discussion. Improved varieties of several crops were developed. The foundation of experimental work on wheat was laid by W. H. Moreland, Director of Land Records and Agriculture, United Provinces. He collected seeds of different varieties and studied their germination, performance, etc. B. C. Burt cultivated Moreland's collection of seeds at the Kanpur experimental farm, first to be set up in India in 1880 by E. C. Buck, and showed the

crop to Albert Howard and Martin Leake. Howards are the actual pioneers in the cultivation of modern Indian wheats. In 1905 Albert Howard and others began work at Pusa and selected Pusa 4 and Pusa 12 varieties of wheat which ultimately proved very valuable. Punjab wheats were studied by David Milne from 1907 and the improved varieties were grown and distributed. Milling and baking tests of Punjab wheat were carried out at Lyallpur Agricultural College established in 1906. In other Provinces also agricultural studies and research started with agricultural colleges as centres. In 1909 an agricultural college was set up at Pune which, in the course of time, carried out studies on virus diseases of chillies, cardamom, and okra; on downy mildew diseases of grapes and their remedy; on the cost of production of crops; on nitrogen changes in rice soils; etc.

Foundations for the classification and breeding of rice were laid by G. P. Hector in 1913 in Bengal and F. R. Parnell in Madras. Hector studied colour inheritance and worked out a method of artificially crossing rice. Parnell worked on similar lines and made a selection of varieties better suited for different parts of Madras. Fruit research at the Chaubatia fruit research station in Uttar Pradesh flourished after 1915 with the improvement in transport and marketing facilities. Sugar-cane research was started by Badami in the Department of Agriculture, Mysore, in 1912.

During this period some changes in the administrative set-up in the Imperial Agricultural Research Institute, Pusa, were effected by entrusting its Director with the duties of the Agricultural Adviser to the Government of India. To the Pusa Institute were later attached the Institute of Animal Husbandry and Dairying at Bangalore; the cattle-breeding and dairying farms at Karnal, Bangalore, and Wellington; a creamery at Anand; and a sugar-cane breeding station at Coimbatore. The Imperial Veterinary Research Institute at Mukteswar was also placed under the control of the Agricultural Adviser.

Recording of irrigation figures in the *Agricultural Statistics of India* began in 1908-09 when about 18·6 per cent of the sown area, covering nearly forty-six million acres, was irrigated. It increased gradually. In 1916 the Bombay Presidency formed a special irrigation division. Prior to 1919 irrigation was a Central responsibility and finance would come either from current revenue or from the famine insurance fund. It may be noted that after the Famine Commission Report of 1901 irrigation had expanded in the Punjab where about 2·5 million acres were under irrigation even in 1887-88.

1920 - 1928

Reorganization of Research: Reorganization of agricultural research in the Provinces started soon after the transfer of agriculture to them. At the Centre

the Department of Agriculture was merged in the Department of Education, Health, and Lands in 1923.

Following the constitutional reforms of 1919, agriculture became a Provincial responsibility, although research activities remained with the Centre through the various Central institutes. The Central research efforts required support in the Provinces, and as such a sum of Rs 2,400,000 was set apart for researches and experimental demonstrations in the Provinces. The aim was to set up agricultural colleges in all Provinces with a three-year course. Experimental farms in the districts would provide the link between the districts and the colleges. A large number of demonstration farms in more or less agriculturally homogeneous areas were proposed to be set up. These experimental and demonstration farms would be under the direct supervision of Directors of Agriculture to be appointed in the major Provinces. These appointments were to be under the Indian Agricultural Service. In pursuance of this scheme, colleges were established or reorganized at Pune, Kanpur, Nagpur, Lyallpur, Coimbatore, and Sabour. The college at Sabour, however, was closed in 1921. Agricultural research was financed by grants to (i) Provincial agricultural departments for specific investigations and (ii) the Institute of Plant Industry, Indore, established in 1924. The Institute also received financial support from many other sources, including the Provincial Government.

During World War I, agricultural work in the Provinces was stalled, although progress so far made in each Province was fairly satisfactory. With the end of the war progress picked up. The Indian Central Cotton Committee was set up in 1920-21 for specialized research on cotton. It drew financial support from the cess on cotton and legal support from the Indian Cotton Cess Act of 1923. The Indian Sugar Committee (1920) obtained in Bengal a wide range of canes and some exotic varieties too. But against highly profitable rice and jute, sugar-cane could not stand.

Royal Commission on Agriculture: In spite of the creation of the Department of Education, Health, and Lands, a strong centre of agricultural research at Pusa, agricultural departments in the Provinces, and provision for research and education in agriculture in the Provinces, low productivity remained the most disturbing feature of Indian agriculture. The Imperial Agricultural Research Institute at Pusa did not attract many students from outside because its agro-climatic conditions were so different from the rest of the country that the students got little experience of value which they could, with confidence, apply to their lands. Until 1923 teaching was confined to short courses in special subjects. In 1923 a two-year post-graduate course was introduced. Coupled with the foregoing factors were the increased population and consequent pressure on land. In this context the Government of India constituted the Royal Commission on Agriculture in 1926 under the chairmanship of Lord

Linlithgow. The Commission made a comprehensive and special study of the Indian countryside and submitted its report in 1928 in which it recognized that the problem of the improvement of agriculture in India was the problem of improving the village life. Commercialization of agriculture through improved marketing and communication, export trade in cotton, jute, tea, and oilseeds, and increased facilities of irrigation in certain parts of the country like the Punjab, no doubt provided incentive to agricultural production. But large-scale farming had no place, firstly, because of the absence of compost and fertilizers, and, secondly, of the lack of knowledge of running large farms. Scientific agriculture, using high-yielding varieties and increased fertilizer doses, was not known. But experience endowed the cultivators with valuable knowledge. The cultivation of rice in the deltas, for example, had reached a marked degree of perfection and the wisdom of many agricultural proverbs stood unchallenged by research. The careful terracing of hillsides, the various methods of irrigation from wells and tanks, the construction of accurately designed channels from the streams to the fields, and similar achievements in improving land disclosed skill, ingenuity, and patient labour of the farmers.

The Commission made an extensive study of the development of education and research facilities and up-to-date progress and achievements in the Provinces in the light of which the most important problems in the field of agriculture, comprising crop and animal production, were projected. It recognized that the creation of the Imperial Agricultural Research Institute at Pusa and the transfer of agriculture to the Provinces, together with the extension of facilities to the provinces to organize research were landmarks in the improvement of agriculture in India. But a review of the progress made showed that the impact of agricultural research was far too small. Lack of sufficient contact between the Provinces, and that between the Provinces and the Pusa Institute stood in the way of the needed co-operation. The Centre hesitated to interfere with the problems of the Provinces. But it was noticed that it could still find ways of co-operation without encroaching on Provincial autonomy. The Government of India had scope of promoting research in agriculture, providing information and co-ordinating Provincial researches. Inaccessibility of Pusa, decline in the prestige of Pusa scientific staff compared with that of the Provinces, more independence inculcated by the Provincial staff, etc. are some of the reasons for the loss in link with Pusa. Pusa, it is to be noted, was primarily a research institute. This fact was also responsible for keeping Pusa aloof from Provincial contacts.

The Royal Commission sought several ways of linking the Centre with the Provinces in the domain of agricultural development. The existence of crop committees was one way; a second way was to transfer control of the Pusa Institute to a quasi-government body in which the Provinces could have their

representatives; a third way was to have a new organization which would have the same relationship with the Centre and the Provinces. The Commission, accordingly, recommended the establishment of the Imperial Council of Agricultural Research. A sum of Rs 5 million was made available to the Council with the provision of additional amounts, as and when funds permitted, for a comprehensive study of agricultural and veterinary problems through the institution of fellowships and scholarships and suitable financial assistance to universities and other research organizations. In order to serve as a clearing house for information on agriculture, the Council was to have its own journal.

The Commission observed that agricultural research was till then considered a responsibility of Government agricultural colleges. In the universities no steps appeared to have been taken to bring agricultural research into close relationship with the other branches of sciences. The vastness of the problems demanded that other institutions, besides Government colleges, should come forward, particularly where a close relationship with the basic sciences could be established. The latter yielded results in other countries, and would do so in India. The universities ought to take up problems of agricultural research brought to their notice by Government agricultural departments. The Commission emphasized the need for interdisciplinary and interinstitutional co-operation and co-ordination in agricultural research.

Trades, according to the Commission, should come forward with funds for research. But cess levied on tea and lac was used more for marketing and advertisement than on research. Jute, facing as it did the danger of competition from synthetic fibres, should receive utmost attention for its improvement through research. The same was true for cotton. Both cotton and jute should be put under separate Central research committees.

The necessity of improvement of cattle by breeding, especially crossbreeding, was greatly emphasized by the Commission. It noted that attempts made in this direction without proper training and knowledge had failed. Such attempts were often vitiated by the desire to get quick success. The importance of fodder and usefulness of silo-making for animal feeding were particularly pointed out. The Commission went into the question of improvement of feeds and fodder *vis-a-vis* higher milk production with the help of cross-bred cattle, the problems of nutrition of animals, and treatment of diseases.

The Commission noted that water reserve of India was considerable and potential existed for hydroelectric power. In fact, Sir Ganga Ram at Renala in the Lower Bari Doab Canal Colony in Punjab did have a hydroelectricity scheme implemented. At that time electric power supply for synthetic ammonia production was not considered commercially viable. The use of electricity for working water pumps was also then considered to be of secondary

importance, primary importance being attached to urban and industrial requirements.

In the opinion of the Commission, demonstrations in Government farms could not be as convincing as they would be in the cultivators' fields. In addition, bulletins in vernacular language and audio-visual media like films, radio, and slide lectures could be effective means of communicating research results to the farmers.

Irrigation: A number of irrigation works which had been started earlier were completed and new projects were sanctioned during the period under review. It may be recalled that after the Famine Commission Report of 1901 irrigation on a vast scale had developed in the Punjab where about 2·5 million acres were under irrigation as early as in 1887-88. Progress of irrigation continued unabated in the Punjab where the irrigated area increased to 10·4 million acres in 1925-26, nearly fourfold in the course of thirty-eight years. Canal irrigation, however, resulted in waterlogging over large areas. It was recognized that drainage was the only answer but the engineers could do nothing. In 1925 a special committee was set up to study the problem. In the Punjab, where irrigation was of supreme importance, a research officer for irrigation was appointed in 1924. Problems of waterlogging, water-level rise, designs of irrigation works, and water-borne silt were some of the subjects of research. In 1925 a research station for irrigation was started in Lahore (now in Pakistan). A research station was set up at Sakrand for studying the irrigation potential of Sukkur Barrage, which was constructed in Sind (now in Pakistan) to irrigate five million acres, the water to be first made available in 1931 and the full quantity in 1935-38. The research station began investigation on the water requirements of wheat, bajra, jowar, rice, and cotton. Stress was laid on berseem as fodder and for maintaining soil fertility. The irrigation department in Bengal was started in 1921, but more to look after navigation irrigation than for crop production. At any rate, the necessary and desirable collaboration between the irrigation and agriculture departments did not exist.

Animal Husbandry: Experiments in sheep-breeding were in progress in the United Provinces during 1912-23. Good results were obtained from careful crossing of better country breeds of Bikaner (Rajasthan) and U.P. with merino and romney marsh. Similar experiments were done at Hissar. Scientific study of animal nutrition began near about the 1920s. At Coimbatore and Lyallpur some work was being done at private level. The Government, however, felt the need for starting an animal nutrition section at the Imperial Institute of Animal Husbandry and Dairying. Animal nutrition studies started at Pusa in 1921 were transferred to Bangalore in 1923. The topics investigated included (i) digestive power of Indian breeds of cattle compared with European

breeds; (ii) digestibility of coarse Indian fodders; and (iii) mineral deficiency in fodders. The number of veterinary inspectors and assistant surgeons in 1927 was 1,400 compared with thirty-two veterinary surgeons in the Indian veterinary service and fifty-two in the Provincial service at the time of the establishment of the civil veterinary department in 1891. Except horses, which were treated by the army veterinary surgeons, and camels locally treated in the Punjab and Sind, other animals hardly received any treatment. Moreover, being located in the district headquarters, the veterinary dispensaries were beyond the reach of cultivators. The total number of dispensaries in 1926-27 was more than 900. Yet this was far from adequate. At least 300 veterinary surgeons and 6,000 assistant surgeons were required to have the minimum of one veterinary assistant to every 25,000 cattle and one veterinary surgeon in each district. The Mukteswar laboratory of the Indian Veterinary Research Institute began producing anti-rinderpest serum in 1901. Afterwards this bulk production centre was shifted to Izatnagar.

1929-1947

The most significant step in the direction of agricultural research during the period under review was the establishment of the Imperial Council of Agricultural Research (ICAR) in 1929 following the recomendation of the Royal Commission on Agriculture, soon after it submitted its report in 1928.

After World War I there was a boom in agricultural production. A large output and trade were the results of this boom during 1925-29, leading to a fall in price. At this time, owing to an unprecedented slump in the U.S.A. in 1929-30, the Indian economy received a jolt, especially in the jute and other raw materials market. This uncertain situation created such an urge for self-reliance that large-scale industries like sugar refining, cement, and paper grew up with Indian capital. The fall in agricultural prices, however, ultimately brought misery to the rural population. Expected relief in the form of tax remission was not liberally available except in the Punjab and U.P. As a result, rural indebtedness doubled to Rs 18,000 million from Rs 9,000 million. While in other countries agricultural prices were raised to alleviate the distress of the producers, measures taken in India in this direction were half-hearted and inadequate. Only in 1937 when the popular ministries took over the administration of the Provinces was some measure of relief assured. Except for sugar-cane, no remunerative price fixation was thought of in respect of agricultural commodities. On the other hand, public investment was reduced by the Government from Rs 814 million in 1929-30 to Rs 334 million in 1933-34. The financing of research was slashed down to merely ·5 per cent of the total

expenditure. It is no wonder then that the impact on agricultural productivity was imperceptible.

By 1932 signs of recovery were discernible. Sugar production increased three times between 1930 and 1937. Substantial increase in production was noted in the case of cotton, jute, paper, etc. The prices did go up by 1939 but were still below the 1928-29 level.

The constitutional reforms introduced under the Government of India Act, 1935, followed by the formation of popular ministries in the Provinces in 1937 brought in their train certain advantages. The setting up of the Reserve Bank of India and the creation of an agricultural credit department in the Bank paved the way for financing agricultural projects, in the absence of which the Provinces could hardly make any headway. The popular governments in the Provinces took certain steps to mitigate rural indebtedness and to bring about social, economic, and agrarian reforms. Some of the important activities in this direction included compulsory debt reduction, licensing and registration of money lenders, rehabilitation of co-operative societies, agricultural marketing facilities, land reforms, and consolidation of holdings. The achievements varied widely in the different Provinces.

RUSSELL'S REPORT

In the meantime, a thorough-going report on the working of ICAR was submitted to the Government of India in 1937 by Sir John Russell, who visited almost all the centres of agricultural research in India including research institutes, Government departmental laboratories, universities, and even individual research laboratories. He not only described the current researches of each centre but also gave an account of their early achievements and progress till about 1937.

Russell's report was specifically concerned with the efforts of ICAR in applying science to crop production in India. About the three stages of development in the application of science to the problems of Indian rural life in general and agriculture in particular, the report had to say and recommend as follows:

(i) In the gaining of knowledge the most important point was good research and training in methodology, rather than results. 'The Council should allocate a definite sum annually for grants to the universities to be used for appointment as research assistants of men actively engaged in scientific research, and that there should be no limitation to subjects of agricultural bearing, as at present.'

(ii) In applying the results of research experimental stations were required, which should aim at straightforward rather than too ambitious schemes. Neglect of this factor and defects in planning

the experiments were responsible for many of the results being of little practical value.

(iii) Extension of the successful trials to the cultivators' fields was the culmination of any meaningful research in agriculture. Many experimental stations reported much higher performance than could be reproduced under field conditions as they prevailed in practice. A large gap existed in translating results from small plots to large fields, and as such many reported experiments were not acceptable to the farmers.

Russell brought in his report these three stages of development to the forefront and suggested how they could be objectively accomplished. He discussed the progress and development of the production of each and every crop, including cash crops, food crops, fodder crops, vegetables as well as fruits and plantation crops and briefly reviewed the work carried out primarily with financial assistance from ICAR in different Provinces and various research centres in the country. The following is a summary of his findings.

At the premier research institute in agricultural subjects at Pusa, H. M. Leake, C. A. Barber, and G. P. Hector were doing fundamental work respectively on cotton, sugar-cane, and rice. Albert and Gabrielle Howard, E. J. Butler, and Maxwell-Lefroy were respectively engaged in researches on wheat breeding, fungus, and insect pests, which were of far-reaching importance. The Provinces, each according to its need and capacity, set up their own research institutes. Universities had begun fundamental work on plant and soil. Other organizations had also their research units. For instance, the Irrigation Research Laboratory at Lahore, the Cotton Research Laboratory at Matunga, the Cotton Field Station at Indore, and the Tea Research Station at Tocklai were doing work in their own fields. ICAR itself carried out some studies on the cost of production of sugar-cane, cotton, and wheat on the basis of which it was observed that cotton was profitable in the canal districts of the Punjab and parts of Bombay; sugar-cane in U.P., Bihar, and parts of Madras, and marginally so in the Punjab; and wheat in the canal areas of the Punjab and U.P. ICAR rightly stressed the statistical control of agricultural experiments; otherwise, lack of proper model would vitiate the results of many costly fertilizer experiments.

Uttar Pradesh: Giving detailed accounts of the research activities in the Provinces, Russell mentioned that in U.P. research on a wide range of subjects was being carried out at (a) Agra College by K. C. Mehta on the occurrence, distribution, spread, and nature of attack of rusts on wheat and other cereals; (b) Bichpuri by C. H. Parr on berseem as a catchcrop and fodder for buffaloes for high milk yield; (c) Shahjahanpur on the effect of fertilizers and irrigation on the yield of sugar-cane; (d) Muzaffarnagar on sugar-cane borers; (e) Bilari

on efficient methods of making *gur*; (f) Kanpur Sugar Research Institute on sugar technology, standardization of sugar, utilization of molasses for road surfacing and industrial alcohol, and as fertilizer and cattle feed; (g) Nagina rice research station on the selection of early varieties of paddy of good quality; (h) Chaubatia fruit research station on all kinds of fruits; (i) Allahabad by N. R. Dhar on photofixation of nitrogen; (j) Banaras Hindu University by B. N. Singh on the physiological effects of fertilizers on sugar-cane and the influence of soil and climatic factors on wheat.

Punjab: In the Punjab research was conducted at several centres. Lyallpur Agricultural College, established in 1906, was engaged in milling and baking tests of Punjab-grown wheat; growing, multiplying, and distributing citrus stocks and grape vines; fruit and vegetable preservation; and selection of promising varieties of rape and mustard. The various departments of the college went on with research on wheat breeding; soils, especially alkali soil reclamation and soil survey for irrigation projects; nutritive value of various local crops; animal nutrition; chemical analysis of sugar-cane samples; molasses in small doses in cattle feed; vegetable rennet from ripe berries of *Withania coaqulans*, a small herb in the Punjab; transformation of nitrogen compounds in soil by microorganisms; cotton boll worms; and locust control as part of ICAR scheme. At Rasalwala work on sugar-cane selection from Coimbatore varieties with manurial experiments on them was done. The Irrigation Research Institute, Lahore, undertook work on subsoil water, salt, and drainage problems associated with heavy use of water, physico-chemical studies of soil, and reclamation of alkali soil. The dry farming research station at Rohtak specialized in soil survey, water penetration into soil, and loss of water by evaporation from soil under different conditions. The Government farm at Hissar did research on grassland by applying phosphates, and on the analysis of fodder and feeding stuff for nutrients. The Punjab University studied the wither tip disease of citrus and the effect of uranium, thorium, cerium, copper, manganese, and zinc on the height and dry matter content of plants.

In Sind work was done at the Sakrand station on the water requirements of wheat, bajra, jowar, rice, and cotton; and on berseem as a catchcrop for fodder and higher soil fertility. The Central laboratory at Karachi supervised a network of locust observation posts set up in 1931. Irrigation facilities made available as a result of the construction of the Lloyd Barrage in 1932 had a striking effect on the yields of agricultural crops in general and wheat and cotton in particular. Quality potato seed production was undertaken at Simla. The Flowerdale station did research on rust-resistant wheat breeding.

Assam: The research station at Tocklai in Assam studied various problems of tea, namely, (i) selection and breeding; (ii) the effect of ammonium sulphate as well as pruning on yield; (iii) diseases and pests; and (iv) their manage-

ment. The Jorhat research station undertook testing and selection of Coimbatore varieties of sugar-cane; manurial experiments on sugar-cane; and entomological, hydrological, and chemical research. The Habiganj rice research station carried out work on flood-resistant varieties capable of rising above water level up to twenty feet at the rate of six to twelve inches in twenty-four hours. At Upper Shillong experiments were conducted on different varieties of potato with reference to their performance and manurial requirements.

Bengal: The cinchona plantation at Mungpoo in Bengal was started under the supervision of C. C. Calder of the Royal Botanical Gardens, Calcutta. At Calcutta University, work was done on soil colloids and their electrometric and physico-chemical properties by J. N. Mukherjee; on algae in paddy fields and the water requirements of rice plants at the botany department; on a comparative study of Indian and Italian silkworms and on the cultivation of edible fish at the zoology department; and on the cultivation of medicinal plants at the School of Tropical Medicine. P. C. Mahalanobis applied statistics to agriculture, village surveys, and experiments at Chinsura on rice and its food value. The physiology of rice plants and the effect of cations and anions on the protoplasm of root hairs were studied at the Vivekananda Laboratory, Calcutta. Experiments on improvement of rice varieties under rainfed conditions were made at Chinsura and Bankura rice research stations. In this connection, use was made of the uniformity trials carried out by Mahalanobis to determine the optimum shape and size of plots, as well as of the complex experiments designed by him to observe the effects on rice of the age of seedling, spacing, number of seedlings per hole, transplanting, broadcasting, and dibbling through varietal trials.

Dacca University (now in Bangladesh) carried out research on the nutrition of rice, its growth rate and chemical analysis in collaboration with Akroyd and Wilson of the School of Tropical Medicine, Calcutta. The nitrogen nutrition of rice and the role and function of algae in nitrogen fixation; respiration of rice plants; mechanical analysis of laterite soils; and general properties of red and lateritic soils are some of the other lines of agricultural research undertaken there.

Bihar: The earthquake of 1934 ultimately led to the shifting of the Imperial Agricultural Research Institute from Pusa to New Delhi in 1935. But wheat breeding for rust-resistance was being done jointly by B. P. Pal and K. C. Mehta at the botanical substation where experiments were also made for late blight-resistant potato varieties. The sugar-cane research station was engaged in (i) the selection of suitable varieties for different areas of the Province; (ii) evolving disease-resistant as well as early and late maturing varieties, and (iii) simple tests for quality assessment and sugar content from early measurements. The Sabour rice research project was concerned with the selection of varieties for

different locations, manurial and cultural experiments, and water requirement of paddy. The Sabour fruit research station undertook research on varietal studies, methods of propagation, vegetative reproduction, the effect of simple growth-promoting substances, and the periodicity of mango-bearing.

Orissa: The Central Rice Research Station in Orissa was engaged in selection of best varieties; collection of strains; fertilizer trials; cultivation practices; and in dealing with problems of water hyacinth propagation in paddy cultivation.

Central Provinces: The Agricultural College at Nagpur did research on the soil survey of rice-growing areas; nutritive values of vegetables; rust-resistant varieties of wheat; improved varieties of gram; root diseases of rice and wheat; oilseeds like linseed, sesame, safflower, and niger; the quality of orange as affected by root stock, the vegetative propagation of orange, its irrigation, pruning, and manuring; and on host plants of rice pests (gangai) getting into the shoot and eating part of it. The rice research station at Raipur carried out investigations on the method of modifying the stem colour of a weed to purple for helping its visual identification and elimination from rice fields, the weed and paddy normally having similar colour. It also undertook a survey of rice soils and made manuring experiments. At the Institute of Plant Industry, Indore, experiments were made on breeding and cultivation of cotton. Among the other subjects studied were soils in relation to crops; compost making by the well-known Indore method; and comparative performance of composts and inorganic fertilizers.

Bombay: The Royal Institute of Sciences, Bombay, studied the suction and osmotic pressures of roots and leaves of rice seedlings. The Agricultural College at Pune investigated virus diseases of chillies, cardamom and okra; the growing of jowar resistant to striga parasite; the cost of production of crops; the downy mildew disease of grapes and its control with Bordeaux mixture; nitrogen changes in rice soils; nutrient absorption by wheat and sunn hemp; changes during the ripening and storage of fruits; and the composition of proteins of cereals and legumes. It also carried out research on agricultural implements. The work at the Ganesh Khind fruit experimental station included studies on cold storage of mangoes, apples and seed potatoes; fruit preservation; vitamins C and A content of mangoes and the suitability of mangoes for export; thermal balance-sheet of solar radiation; water balance-sheet; soil temperature at different soil depths; porous candle method of determining soil moisture; microclimatic measurements; and the effect of rainfall on cotton yield based on the study of twenty-eight years' data. At the Padegaon sugar-cane investigation centre research was done on the effect of soil condition and water supply on the growth of sugar-cane; genetic soil survey; and alkaline soils and their amelioration.

Mysore: The department of agriculture started investigations on sugar-cane as early as 1912, establishing homozygous canes by continuous selfing and isolating several vigorous canes from X-radiated mutants. The department also worked on plant products as fish poisons and insecticides, and on remedial measures for sandal spike disease.

Madras: At the University of Madras research was undertaken on the cultivation of algae in paddy soil and tanks; enzyme hydrolysis of animal and vegetable proteins; nitrogen metabolism of germinating seedlings; the life history of fishes along the coast; and the culture of crops and other fresh-water fish. The Presidency College, Madras, studied the morphology and physiology of sugar-cane and sorghum hybrids, medicinal plants, and plant products. The tobacco research station at Guntur experimented on the growing of Virginia tobacco and the chemical composition of cured tobacco. The nutritional research laboratory at Coonoor probed the nutritive value of foods. The potato breeding station at Nanjanad carried out research on potato breeding and the cultivation of three crops in a year. The sugar-cane breeding station at Coimbatore started work in 1912 on breeding suitable and improved varieties previously imported from Java and Mauritius. C. A. Barber developed cross-fertilization techniques and crossed indigenous varieties with wild saccharum plants to produce an entirely new set of varieties of great vigour. Venkataraman developed the technique still further. Janakiammal made cytological studies of sugar-cane. Studies of the chemistry of sugar or carbohydrate formation in the leaf and supplemental irrigation of sugar-cane were undertaken at Anakapalle and Guddiajatam. Research was done in Madras on many other crops. As early as 1913 F. R. Parnell characterized varieties of rice by colour analysis of paddy. Other works on rice included the collection of 1,300 rice varieties of which 500 were pure lines, and selection of suitable varieties for different parts of Madras; development of new varieties by X-radiation; and manurial experiments showing the beneficial effects of green manuring and ammonium sulphate. Research on millets was directed to the selection of disease- and drought-resistant varieties and crossing with disease-resistant African varieties. Five hundred varieties of banana were surveyed, out of which fifty to sixty types were selected as promising. Research on coconut was made to forecast future performance of seedlings on the basis of the time of germination, rate of production of leaves and increase in girth, height of stem, etc. Factors affecting the quality of copra and oil were also studied. Research was done on cotton, groundnut, and sunn hemp. Diseases of coconut, especially leaf rot and wilt or root disease, were studied at Travancore (now in Kerala State).

In addition to the foregoing survey of the research activities at different centres and in Provinces all over the country, Sir John Russell gave in his report a neat summary of the research and developmental aspects

of different crops till 1937. The highlights of this summary are given below.

(i) *Tea, Cotton, Sugar-cane*: Organizations from the production to marketing of tea and cotton were quality-oriented, keeping the export market in view. In the case of sugar-cane, the Government decision to promote production of white sugar created a favourable situation. The plant breeding work at Coimbatore under the able guidance of Venkataraman was responsible for many improved varieties of sugar-cane which were grown on nearly 3·01 million acres out of 4·14 million acres under the crop. The production of molasses increased more than five times from 1930-31 to 1935-36 as a result of which imports were negligible. The Imperial Sugar Research Institute at Kanpur improved efficiency of recovery of sugar from 80 to 90 per cent.

(ii) *Cereals—Rice*: The schemes of rice research co-ordinated by ICAR at Coimbatore (Madras), Nagina (U. P.), Chinsura, Bankura, and Dacca (Bengal), Habiganj (Assam), Sabour (Bihar), Raipur (C. P.), and Karnal (Punjab) were collecting useful data on the botanical and agricultural properties. But the manurial experiments suffered from faulty designs. Information on water requirement and diseases of rice was lacking. The yield as well as area under rice showed a declining trend.

Wheat: Punjab and U. P. led in wheat area and production, but the yield was highest in Bihar and Orissa (about 39 quintals per acre) followed by U. P. (about 36 quintals per acre) and Punjab (about 33 quintals per acre). Nearly half of the total area under wheat was irrigated. The production during the two decades ending 1930-31 showed increase, but there was gradual reduction of export indicating higher internal consumption. The opening of Lloyd Barrage and the completion of Sutlej valley scheme ensured higher production so much so that a large surplus was feared and hence production was not positively encouraged.

Barley: Barley grown on 6·5 million acres had a good export market in England for breweries. But owing to a better variety available from California, the export market for Indian barley did not show expansion.

Millets: The water requirement of millets being low, large areas were sown with this crop. For improvement of varieties millet sections were established in Coimbatore and Indore. Experimental schemes were sanctioned in Nagpur, Lyallpur, Bombay, and C. P. as part of dry farming work. Some improved varieties were obtained but they did not spread much.

(iii) *Pulses*: Even though good sources of protein, pulses received no attention from ICAR at that time.

(iv) *Vegetables and fruits*: Research work on potato started well but others were neglected. The awareness for fruits as sources of essential vitamins and minerals was slowly growing, but no organized research for improvement and

increased production was afoot, mainly because of lack of marketing and processing facilities. In fact, the acreage under vegetables and fruits showed a steady decline during the two decades ending 1934-35.

(v) *Oilseeds*: Oilseeds occupied about 5% of the total sown area. Considerable amounts of oilseeds, particularly groundnut, castor, and linseed, as well as their cakes were exported.

(vi) *Fodder Crops*: Fodder production was in a poor state, as a consequence of which improvement of livestock suffered. Forest grazing was, therefore, resorted to. As a result, denudation of forest cover and soil erosion set in especially in the foot-hill areas. Berseem as a fodder was grown successfully on saline lands, and also under irrigation. It ensured soil fertility and higher yield of buffalo milk.

(vii) *Tobacco*: Export quality tobacco was an incentive but for this purpose buyers' preference had to be ascertained.

RESEARCH AND THE PEASANTRY

Success in all the aforementioned research efforts paled into insignificance in the background of abject rural poverty, malnutrition, and disease. Cultivators could hardly make use of the research results which were thus rendered meaningless. Peasants, with small holdings incapable of providing the requisite inputs and wanting the resources to market their surplus, were never the aims of scientific research. Urban interests, on the other hand, dominated all planning and policies. Strengthening the rural sector by giving subsidies, reducing interest rates, deferring repayment of loans, organizing co-operatives and marketing boards, restricting imports to encourage home products, etc. ought to have been some of the measures adopted, particularly after the depression years, as was done in other countries.

Nevertheless, the researches carried out in various parts of the country resulted in the identification of the factors conducive to higher crop yield. Of these the following were actively pursued with varying degrees of success: (i) adoption of improved varieties of crops—although the genetical aspect was slowly gaining ground, such adoption, except in the cases of sugarcane and jute, was poor owing partly to non-availability of improved seeds and partly to lack of information; (ii) control of pests and diseases through (a) the evolution of resistant varieties exemplified by the rust-resistance study of wheat by K. C. Mehta, (b) changing cultivation practices and soil conditions as shown by Andrews at Tocklai in the case of tea and by P. B. Richards in the case of sugar-cane, (c) use of chemicals preferably of vegetable origin, and (d) biological control; (iii) better water management and designing of crop schemes and control of soil salinity by means of improved drainage; (iv) prevention of soil erosion by taking precautions against defo-

restation, jhuming, grazing on slopes, etc.; (v) better manuring and use of fertilizers with emphasis on composts and green manures; (vi) soil analysis together with experiments in cultivators' fields; and (vii) better crop sequence in accordance with the fertilizing effect of certain crops on the succeeding one.

Although the important factors determining improvement of crop yield were fairly well identified as early as in the 1930s, scientific agriculture did not make much headway in India as the farmers or their wards did not get the benefit of agricultural education for adopting farming as a profession.

Attempts made by Fazli Hussain in the Punjab and Sind at settling educated farmers by offering certain incentives were, however, exceptions. Two other factors also obstructed the progress of agriculture in the country. These were rural indebtedness and fragmentation of holdings. The Central Banking Enquiry Committee of 1930 estimated that rural indebtedness was about Rs 9 billion. This burden of debt acted as a disincentive to the adoption of more sophisticated technologies because of the obvious uncertainty of the risk involved. The only answer to this was supply of agricultural credit through co-operatives. But except in certain Provinces like the Punjab and Bombay, nowhere did co-operatives find strong roots. Fragmentation of holdings was another disincentive to improvement of agriculture. In the absence of legislative measures for consolidation of holdings, the co-operative movement was the answer to this problem. Often good leadership and persuasion at the village level could induce co-operation. In this connection, the work of Daniel Hamilton in the Sunderbans area of Bengal was an example.

WORLD WAR II AND AGRICULTURE

The period covering 1939-47 saw considerable reorganization of agricultural administration and research. With the outbreak of the war, the Government launched a vigorous drive to increase food production and introduced price control and restriction on the movement of foodgrains from one Province to another. Export of jute, cotton, and groundnut fell substantially during 1938-41 leading to the regulation of area under the cash crops, particularly jute in Bengal. Higher prices at the beginning of the war induced cultivators to produce more but the imported supply ceased altogether. On the other hand, demand for foodgrains increased because of the needs of defence personnel. As a result, prices rose. These and other factors led to a rethinking on the part of the Government to take firm steps to increase agricultural production. The starting of the grow more food campaign in April 1942 was one such step. This campaign showed that given incentives—price, inputs, marketing facilities, etc.—production could be boosted up to a higher level. Administration of food became an important concern of the Government, but not much headway could be made. The contemplated basic plan which envisaged a knowledge of the surplus

and deficit Provinces on which food movement could be planned was sabotaged by the Provinces themselves by overestimating their deficits and requirements of food. The subsequent decision of the Government in June 1943 allowing free trade in Bengal, Bihar, Orissa, and Assam was followed by a similar step throughout the entire country, barring the Punjab and Sind. The Foodgrains Policy Committee set up in July 1943 under the chairmanship of Theodore Gregory recommended in September 1943 the rationing of foodstuffs in all big cities. In the meantime, the decision on free trade was revoked. Partly due to the war and partly due to natural calamities, the foodgrains supply was precariously hampered. Added to this was administrative inefficiency in dealing with food distribution.

A famine, essentially man-made, of unprecedented severity broke out in Bengal in 1943, and the Famine Enquiry Commission (1944) headed by Sir John Woodhead suggested a number of measures to increase agricultural production. While implementation of the recommendations of the foodgrains policy committee for controlled distribution of foodgrains was speeded up, stress was also laid on higher agricultural output. To this end, indigenous production of fertilizers was the first logical step. The factory of Fertilizers and Chemicals (Travancore) Limited, the first to start fertilizer manufacture in the country, went into production in 1947. The involvement of the Central Government in the grow more food campaign during 1943-47 was a marked departure from the past. The campaign aimed at increasing food crop area in preference to cash crops; intensive cultivation employing fertilizers and irrigation; and extending cultivation to current fallows and culturable wastes. As a result, tubewell sinking, lift pumps, and provision of electricity were matched, followed by land reclamation for which a central tractor organization was set up in 1946. The evaluation of the grow more food campaign during 1946-47 revealed that its progress suffered a set-back owing to bad weather, the prevailing uncertain political situation, communal riots, and ineffective control of supply and prices. Uncertainty in the prices of food crops led farmers to divert land to the cultivation of more profitable crops.

In 1945 the Department of Education, Health, and Land was reorganized into three departments, one of which was that of agriculture. Soon after the end of the war the Government of India started thinking of reconstructing the economy of the country, and accordingly a policy committee on agriculture, forestry, and fisheries was appointed. This committee recommended the setting up of a number of sub-committees on such subjects as agricultural prices, credit, marketing, and fisheries development. All these were merged with a separate department of planning and development which had been established in 1944. Each of the sub-committees made thorough sectoral studies of the agricultural situation and made a number of recommendations to improve it.

Fishery Development: The establishment of the deep sea fishing station at Bombay in 1946 was an important step in the field of fishery development as it was aimed at producing suitable power craft and equipment for fishing, exploring new fishing grounds, and training personnel for manning fishing craft. Two research institutes to deal with the problems of inland and marine fisheries—the Central Inland Fisheries Research Institute, Barrackpore, and the Central Marine Fisheries Research Institute, Cochin—were subsequently set up in 1947. The Plant Protection, Quarantine, and Storage Directorate was established in 1946 to co-ordinate activities relating to pest and disease control in the Provinces. The locust warning organization created in 1939 merged with the new directorate.

Commodity Research: The Government of India established some centres of research relating to agricultural commodities. The Central Rice Research Institute, Cuttack, was set up in 1946. Besides this, the following Central commodity committees for promoting the development of some cash crops were established: sugar-cane committee (1944), tobacco committee (1945), coconut committee (1945), and oilseeds committee (1947). In the field of forest research and development the Forest Research Institute, Dehra Dun, established in 1906, was expanded and reorganized with a view to increasing the production and ensuring better utilization of forest products.

With independence, the immediate task of the Government was to increase domestic production of all agricultural commodities. The grow more food campaign, extended for five years from 1946, was placed on a planned basis from 1947-48. The foodgrains policy committee of 1947 recommended greater attention to minor irrigation works; development of local manure; distribution of improved seeds; production of fertilizers; and the setting up of a central organization for undertaking reclamation and development of large blocks of cultivable waste lands. In view of the importance of fertilizers in increasing soil fertility, field trials were conducted by A. D. Stewart, who recommended in his report of 1947 that simple experiments in cultivators' fields, soil surveys, and laboratory investigations should be carried out. In pursuance of these recommendations, ICAR initiated a scheme under a series of three-plot trials in cultivators' fields. After a three-year trial period a revised programme was formulated covering (a) soil survey and mapping; (b) radiotracer investigations for intake of phosphorus; (c) agronomic trials to observe fertilizer response; and (d) development of rapid soil tests for N, P, and K to correlate the test data with crop response.

ANIMAL HUSBANDRY

The research efforts and achievements in the field of animal husbandry during the period 1929-1947 were comprehensively dealt with in an ICAR

review. It included breeding, nutrition, diseases, dairy industry, sheep and wool, and poultry keeping. Some of the more important research findings highlighted in the review are summarized below:

Before ICAR was established in 1929, cattle-breeding activities were limited to the Central and Provincial Government cattle farms. The latter were engaged primarily in the distribution of farm-bred 'approved sires' and widespread castration of scrub animals. There were no systematic studies regarding the quality of breeding bulls. Nor were records kept of their performance. Realizing these lacunae, ICAR started the maintenance of central herd-books for all the well-established breeds of cattle in the country. The actual work of maintenance, following the international standard, began in 1941. These data referred to herds which were maintained in Government farms, but no records were available regarding the village cattle which constituted the bulk of the cattle population of India.

Cross-breeding was probably first started by the military farms located all over the country in different climatic and environmental conditions. It was established after detailed experimentation that the productive capacity of the animal was optimum with five-eighths of its blood drawn from foreign stock. The cross-breeds were found to be more susceptible to diseases and demanded superior management and feeding. Because of these factors, cross-breeding did not find favour outside of military farms. The civil farms gave up cross-breeding work and devoted themselves to selective breeding of indigenous cattle. The first successful insemination of cows was done in 1939 at the Mysore palace dairy farm. Systematic investigation on artificial insemination was, however, started in India in 1942 under an ICAR scheme at the Imperial Veterinary Research Institute (IVRI), Izatnagar. The organizational aspects of managing large-scale insemination were studied at four developmental regional research stations established between 1945 and 1947 at Calcutta, Patna, Montogomery (now in Pakistan), and Bangalore. The experiments carried out at these centres demonstrated the feasibility of artificial insemination by the fact that the number of services for conception varied from 1·42 to 1·50 for buffaloes and 1·33 to 1·57 for cows. An immediate follow-up of these investigations was the 'key village scheme' introduced by the animal husbandry departments. To supply semen from Jersey bulls for artificial insemination, a semen bank was opened at the National Dairy Research Institute (NDRI), Bangalore. Regional centres were also set up at Pune, Calcutta, Cuttack, Madras, and Izatnagar to undertake research on a regional basis. At IVRI, a number of problems relating to artificial insemination were studied by Bhattacharya and co-workers.

Blood grouping of animals was first attempted in this country at IVRI in 1942 by Balwant Singh. He tried to correlate the frequency of A, B, AB, and O analogous to human blood groups with breed characteristics. Similar studies

were made on horses. A more comprehensive work was taken up at IVRI under a scheme sponsored by ICAR.

Minnet and co-workers started animal climatological studies in 1941. They observed that wetting the bodies of milch buffaloes during hot months ensured steady milk supply. The semen quality was found to be dependent on ambient temperature, being best in spring (February-April) and worst in autumn (August-October). The effects of temperature and humidity on the health and productive capacity of cross-bred cattle and of buffaloes were extensively studied at IVRI. The parameters measured included physiological reaction, blood and milk composition, feed and water intake, urinary output, and activity of endocrines.

Research on various problems of animal nutrition was carried out at the animal nutrition division of IVRI under many research schemes financed by ICAR. Amongst the important subjects studied were: composition and nutritive values of common livestock feeds available in different parts of the country; nutritional requirements for the prevention of various diseases of animals; computation of balanced ration, including protein and calorie requirements, of both indigenous and cross-bred cattle; diseases caused by mineral and vitamin deficiency; replacement of concentrate mixtures by green fodders; plants and minerals (particularly cyanide and fluoride) toxic to livestock and methods of preventing and removing toxicity; economic methods of calf-rearing; methods of fodder conservation; processing of feeds for improving their nutritional value and the effect of feeds on the quality of milk and butter; and utilization of waste agricultural crop products as cattle feed.

The veterinary research work at IVRI was of high quality and the method of detection and prevention was systematized. The important diseases investigated at IVRI and its achievements in regard to their prevention included an adjuvant vaccine for haemorrhagic septicaemia, *Clostridium chauvoei* as the causative organism for black quarter and a prophylactic vaccine for it; a prophylactic vaccine for anthrax; tuberculin test showing affectation of cattle and buffalo but negative tests for tubercle bacilli in milk; an improved diagnostic test for Johne's disease; causative factors—of bovine mastitis; bovine abortion and its causative factors; preparation of mallein for diagnosing glanders in horses; transmission of rinderpest and preparation of prophylactic vaccine with goat tissue virus alone in dried form; classification of foot and mouth disease virus and preparation of crystal violet vaccine; culture vaccine for rabies; preparation of effective vaccine for Ranikhet disease of poultry; and preparation of vaccines for fowl pox virus.

Dairy research was aimed at higher yield of better quality milk per animal. For this purpose, breeds and feed management were the most important factors to which reference has already been made. Processing technology, transport,

and distribution also played important roles in the marketing of milk. Scientific knowledge was required for improving the quality, shelf-life, and acceptability in the market of milk products. Extensive studies were made on the bacteriology of milk and milk products, and on the composition of milk in terms of nutrient constituents.

Wool: Some improvement in the quality of wool obtained from local sheep was brought about through cross-breeding with merino early in the nineteenth century at the sheep-breeding areas of Pune and Ahmednagar districts. It, however, lasted not more than ten years. The Amritahal farm at Mysore had similar experience. A number of sporadic attempts to improve the breed were also made in the first half of the nineteenth century in the Punjab, Bengal, and Madras. They were mostly done by enthusiastic British officers and were discontinued with their departure from service. In the first decade of the twentieth century, programmes of cross-breeding of local sheep and the Bikaner breed with merino and Romney-Marsh rams were undertaken in many farms in U. P. But no stable results were obtained and hence the programmes were abandoned. At Hissar the crossing of Bikaner breed with merino resulted in a type of flock christened Hissardale. It was presumed that the type was fixed at three-fourths merino blood. Pilot experiments to breed superior sheep were started at Hissar and Pune in 1938 and continued till 1949. Experimental flocks were also maintained at Mysore and Madras. Considerable importance was attached to the rearing of exotic breeds in Kashmir. On the basis of experiences gained at these stations, it was decided to develop indigenous types in the plains and restrict cross-breeding to the temperate Himalayan region and to the sheep rearing areas of the western parts of the Deccan plateau. Selective breeding was restricted to the Deccan, Bikaner, Kutchi, and Lohi sheep for the purpose of improved wool production. The exotic breed for cross-breeding was inevitably merino. Breeding sheep for meat production was also taken up with the Nellore, Mandya, and Bannur sheep of South India. Exploratory trials were undertaken to cross-breed the Bannur sheep with the British Southdown rams and Somali rams from Barbera for mutton improvement.

Poultry: In the course of a survey of the whole country during 1941-48, freedom from salmonella was indicated. In March 1949, however, a large proportion (50 per cent) of chick mortality in North India was recorded as due to this disease. The disease was, however, controlled. Large-scale studies showed that Ranikhet disease was controlled by routine vaccination of chickens aged 6-10 weeks. Spirochaetosis (tick fever), which caused widespread and heavy losses, was transmitted by the vector tick. Injection of healthy birds with the blood of infected ones protected the former for about six months. Intramuscular injection of sulfarsenol or soamin cured the disease, if given at early stages.

The importance of providing a sound health cover for the livestock was

gradually realized. In 1928 there were only 904 veterinary hospitals and dispensaries in British India, which on the strength of the recommendation of the Royal Commission on Agriculture were increased in number to 2,655 at the end of the first five-year plan. The establishment of hospitals and dispensaries was not enough unless backed by appropriate medicines and vaccines. To this end the attention of the Government was directed as early as 1898, soon after the establishment of IVRI. In 1924 a well-organized centre for production of veterinary biologicals was set up at Izatnagar. Recognizing the difficulties of serving the entire country through one centre, steps were immediately taken to set up centres at other convenient locations. During the period 1926 to 1947 six more centres came into existence in Mysore (1926), Madras (1932), U. P. (1945), Orissa (1946), Andhra Pradesh (1947), and Maharashtra (1947).

POST-INDEPENDENCE PERIOD

The partition of India in 1947 caused considerable imbalance in agricultural production. With the appointment of the Planning Commission in 1950, and the institution of five-year plans, development of agriculture (including animal husbandry, forestry, and fishery) assumed greater significance in the matter of stabilizing the country's economy.

Research support to agriculture came by way of the eastablishment of institutes and the formation of commodity committees by the Government. Agricultural research had hitherto been restricted to certain crops and institutions. There was not much co-ordination. Nor was there any attempt to apply research results to farmers' fields for production purposes. ICAR had to assume the role of co-ordinator as well as promoter of agricultural research. This resulted in the all-India co-ordinated research projects, which paved the way for a better understanding of locational and regional problems and their remedies. Projects for the intensification of regional research on cotton, oilseeds and millets, and an all-India maize improvement scheme were accordingly undertaken.

Soon after were established agricultural universities based on the recommendations of the Indo-U.S. teams with the concept of integration of teaching, research, and extension as their key role. The first of these universities, wedded to integrated teaching, research, and extension, was set up in 1960 at Pantnagar in the terai area of Uttar Pradesh. Extension work, key to transfer of research results to the farming community, had so far been neglected and left to uninspired workers. Field demonstration, training of farmers, transfer of know-how from the laboratory to the land, organized visits of farmers to scientifically managed farms, etc. have no doubt been introduced. But the total achievement in this important sector is still far below requirement. In fact, research and

teaching have been rendered ineffective by the failure on the extension side.

The rise in production during 1951-67 was the result of increasing irrigation, better agricultural practices, popularization of improved seeds of some crops, and wider use of chemical fertilizers. Other measures such as soil and water conservation, land development, consolidation of holdings, provision of agricultural credit and marketing facilities, price incentive, education, and research lent support to production. The period 1967-74 saw agricultural development based on the adoption of new technology to harness irrigation water, and the use of quality seeds, chemical fertilizers, and wide-ranging pesticides. The rate of rise in production was 4·1% in the first plan period; but it decreased to 3% in the second and third plan periods and still further to 2·2% in the fourth plan period. The decline was partly due to fall in the area under cultivation. But the main reason was that the vast majority of farmers being poor could ill-afford the relatively costly new technology. Moreover, the inputs were not readily available in remote areas owing to lack of transport and other infra-structures. Obviously, the new technology was not appropriate to the prevailing socio-economic context and could not be made so by extension innovations whatsoever.

The pre-plan period witnessed a large population of animals of poor quality suffering from lack of nutrition and health care. Livestock rearing being subsidiary to crop production, programmes of breed improvement, provision of food and fodder, and health measures went by default.

High-yielding Varieties: Considerable concern was shown by the Government in the face of these diverse challenges and the spells of stagnation in agriculture, particularly during the sixties. Some degree of success in the production of one or two cereal crops and some non-food crops was achieved; but they were not enough to raise hope. Critical shortages of fat and protein loomed large. The improvement was, however, spectacular in the wake of the introduction of Taichung Native I and IR-8 varieties of paddy from the International Rice Research Institute (IRRI), which have got the dwarfing gene. New varieties were produced by manipulating IR-8 to suit diverse local situations. Nearly seventy such varieties have so far been released. The coverage of the total paddy area of thirty-eight million hectares by the high-yielding varieties has not been uniform owing to lack of adequate inputs.

Wheat cultivation has set a better record following the introduction of the Mexican varieties. Here also, new varieties were developed to suit certain areas, and to make the varieties disease-resistant to some extent, particularly against rusts. The multiline approach to breeding has shown some definite advantages in the matter of combating disease and stabilizing production. It is, however, interesting to note that none of the varieties perform in farmers' fields as well as it does in national demonstrations. The reasons for this failure deserve deeper

search. Maybe, one of the ways of a breakthrough in production lies in this direction.

High-yielding hybrids of sorghum, evolved by using cytoplasmic male sterile line as female parent, are capable of withstanding to some extent climatic shocks but are susceptible to shootfly and gall midge. Likewise, hybrids of pearl millets, which are generally rainfed crops, can resist climatic variations.

Since 1957 the all-India co-ordinated maize improvement project has so far released twelve hybrids, six composites, and three nutritionally superior varieties. The departments of agriculture in the States have also released fifteen composites and two hybrids. Though commonly a kharif crop, its performance is better. Pulses are typically tropical crops, and occupy an important position in Indian diet. The improvements achieved under the all-India co-ordinated pulse improvement project are not yet so hopeful. Many potentially high-yielding varieties of castor, rapeseed, mustard, groundnut, safflower, sunflower, linseed, taramira, toria, and raya have been evolved. Of these the most important is groundnut, but shortage of seed is standing in the way of large-scale production. Perennial sources like cocount and oil palm are of great importance, but their production is hampered by diseases.

Potato research has yielded high dividends and the output has been doubled in the course of thirty years, making India a leading potato producer. The main achievements are the breeding of Kufri varieties suiting almost all possible growing conditions, and development of seed plot technique for disease-free seed. Soyabean, an imported oilseed from the U.S.A., has not become a commercial possibility except in certain regions of the terai in U. P. and M. P. But an all-India co-ordinated project is trying to make it acceptable in view of its high oil as well as protein contents.

The Sugar-cane Breeding Institute at Coimbatore is a pioneer institution to evolve new varieties of sugar-cane. Coimbatore varieties now occupy nearly 70% of the area under sugar-cane. More than twenty other countries also use Coimbatore canes. The Institute has tried several short-duration varieties (eight months instead of fourteen to eighteen months) which are of higher sucrose content. In the fields of fruits like mango, grape, papaya, apple, and vegetables of different kinds research work has been directed towards good quality as well as high yield. Some promising varieties are in commercial use and others are in the pipeline. The all-India co-ordinated cotton improvement project has got thirty research centres spread over different agroclimatic regions in the country. A large number of varieties having improved quality and better yield have been released, including intrahirsutum and interspecific varieties. Jute varieties suitable for different agroclimatic conditions and for multiple cropping have been released by the Jute Agricultural Research Institute at Nilgunge off Barackpore in West Bengal. There is, however, a technological gap in the

area of retting, which, if properly done, may greatly improve the quality of fibre.

Soil Survey: Soil survey and soil fertility research including availability of major and micro nutrients have been undertaken on a comprehensive scale, providing thereby an excellent support to the new technology. Cultural practices like multiple and relay cropping and intercropping are being standardized for the purpose of optimizing the use of land, water, and other inputs. Suitable packages of practice have been worked out on the basis of these researches which are of great practical value. Intensive agriculture requires use of machines and tools for land preparation, sowing, harvesting, threshing, etc. and also for processing of agricultural products. Agricultural research institutes and universities are engaged in developing such machines and tools suitable for different crops and local situations.

Forest Conservation: Forest denudation on a largescale and the consequent soil erosion have been alarming. The reasons for the denudation are increasing demand for fuel wood, paper pulp, and timber. Clandestine felling and no replanting have brought forestry resources to a dwindling and critical situation. Aggressive programmes for afforestation were, therefore, launched but the demands, both regular and clandestine, have been increasing at a more rapid pace than replenishment. The investments on forest research and development have not been commensurate with the magnitude of the problem. The Forest Research Institute and College, Dehra Dun, has not been able to fulfil its objectives, according to an assessment made in 1964. Its training courses have, however, earned considerable reputation. Closely connected with forest development is the question of wild life preservation and management. Many sanctuaries have come up in different parts of the country, e.g. Corbett Park in U. P., Taroba and Kanha National Parks in M. P., Madumalia National Park in Tamil Nadu, Jaldapara Game Sanctuary in West Bengal, and Kaziranga Game Sanctuary in Assam. The Indian Board for Wild Life was set up in 1952. It has been instrumental in executing the 'Project Tiger' programme, in addition to setting up 126 sanctuaries and five national parks in the country.

Animal Husbandry: The broad principles of producing and feeding cross-bred animals for better performance have been laid down for the breeding of efficient livestock. Because of weak oestrus in buffaloes, artificial insemination is less successful if oestrus is not properly detected. Researches on locating the time of oestrus by determining the progesterone level of plasma and, alternatively, on inducing oestrus by using chemicals like prostaglandin F_2 alpha and estrumate have been carried out with limited success. The problem of preserving buffalo semen for artificial insemination work has been solved by producing frozen semen after nearly two decades of research. Suitable dilutors have also been

prepared, which show fairly good recovery of sperms. Sheep and goats constitute an important group of livestock, closely related to the economy of arid, semi-arid, and tribal areas. Some useful breeds have been identified for the purpose of meat and wool.

Scientific research on poultry development started in an organized fashion with the establishment of the poultry research division of IVRI. The introduction of deep-litter and cage systems of poultry keeping, production of balanced feed, multiplication of exotic and high-yielding layers, health care, etc. have made enormous impact on commercial poultry farming in the public and private sectors.

The occurrence of well-defined breeds of milch and draught animals in specified tracts for each class is the handiwork of modest farmers and environmental factors. The occurrence of poor 'nondescripts' in regions of high rainfall and paddy cultivation and in the coastal regions of India is due to chronic underfeeding, malnutrition, and indiscriminate breeding. Early attempts to breed camels, mules, horses, and cattle were, as already pointed out, intended to meet mostly military needs. The division of animal breeding and genetics of IVRI has systematically explored the possibilities of artificial insemination on the basis of the investigations of semen characteristics of different breeds of cattle, buffalo, goat, sheep, white leghorn, and country birds. The success of all-India programmes is to a large extent attributed to thorough investigations and careful planning. On the basis of many experiments carried out with cattle, buffalo, sheep, and goat, their nutritional requirements were assessed and balanced diets formulated so that their health as well as milk and wool production could be maintained at a high level. Many deficiency diseases have been identified and their remedies evolved. IVRI has developed a vaccine against rinderpest and the technique of its large-scale production by means of tissue culture. It has also produced the polyvalent hydrogel vaccine for foot and mouth disease of livestock and stabilized the production of rabbies vaccine.

Research centres spread over the whole country are working on various other diseases of livestock, including contagious bovine pleuropneumonia, loptospirosis, salmonellosis, tuberculosis and Johne's disease, mastitis, and brucellosis. The FAO/WHO Brucella Reference Centre, catering for the needs of the countries of South-East Asia region, is located at IVRI. The National Brucella Reference Centre is also located there. ICAR has established a network of centres to study parasitic diseases of cattle, goat, and sheep, and to ascertain their remedies. Improvement in the country poultry has been effected by a process of feeding, culling, and selective breeding for high egg-laying capacities. The keeping quality of eggs could be increased by lime sealing of heat treated eggs. The vaccine for Ranikhet disease was evolved by IVRI. Immunity is produced in three or four days after vaccination and lasts for

three to four years. Intranasal application of the UK F-strain followed by the Mukteswar strain between six and ten weeks gives life-long immunity. Fowl-pox can be eradicated for life by administering vaccine developed at IVRI.

Pisciculture: Significant advances have been made in the development of designs of trawlers and fishing gears as a result of researches carried out by the Central Institute of Fish Technology. It has also developed some standardized methods of processing and preserving fish. The Central Inland Fisheries Research Institute has established the methods of breeding, rearing, and management of both captured and culture fisheries in fresh and brackish waters. Aquaculture techniques of induced breeding by pituitary hormone administration of major carps and Chinese carps and of bundh breeding of grass carp and silver carp have opened up new avenues of fresh-water fish seed and fish production. The development of a hatchery provided with circulating water and a package of practice of composite fish culture have made fish production commercially viable under pond conditions.

Special Areas Farming: Soon after independence research efforts were also directed to the development of arid zones, dry lands, hill areas, salt-affected lands, and tribal areas. The Central Arid Zone Research Institute (CAZRI) has made a thorough assessment of the natural resources of Indian arid zones together with areas affected by salinity and alkali, the land use pattern of these zones, soil fertility level, water resources, livestock population, cropping systems, etc. in order to make effective utilization of them. CAZRI has identified suitable crops and evolved economical cropping and water harvesting systems.

The research scheme of ICAR relating to dry farming, conducted for ten years (1933-43), recommended bunding, deep ploughing, use of farmyard manure, and low seed rate. The improvement in yield was, however, marginal. Later researches suggested that in view of the short period of availability of water, crops which matured within this period would grow favourably. Such short-duration crops became available by 1965, the most important being jowar CSH-1; bajra HB-1; and cotton -PRS. They could really make a breakthrough in dryland agriculture. The all-India co-ordinated research project for dryland agriculture has systematically made use of jowar, bajra, and cotton varieties bred for low rainfall conditions. Twenty-three research centres located at various dryland areas are collaborating in this project. During the last one decade or so, quite a few crops giving good yields and suitable for different areas have been identified. The cultivation practices for each area have also been evolved.

An alternative to jhuming in the hill areas has been suggested in which the lower portion of a hill slope (approximately 1/3 area) is bench-terraced for normal agriculture, mostly paddy or maize cultivation; the mid-portion, also comprising 1/3 area, is half-moon terraced and used for horticultural crops;

while the steepest slope is utilized for forest plantation. This pattern of land utilization conserves soil against erosion and gives economic returns.

Salt-affected areas are the product of irrigated agriculture with faulty drainage. Soils turned sodic may be reclaimed by the use of gypsum, the technology for which has been successfully developed by the Central Institute for Soil Salinity Research. It has evolved packages of practice suitable for specific situations. In the saline areas salt-tolerant crops seem to work better.

The introduction of scientific agriculture in the tribal areas poses many difficulties. The studies so far initiated in this regard suggest that in keeping with the traditional beliefs of these people, it would be expedient to work within the existing framework of farming practices, and to introduce improvements gradually. Fruit trees, pig and poultry farming, and mixed farming fit in with tribal situations. Not many scientists have the inclination and patience to work in such difficult areas, and hence not much success has been achieved in the development of tribal areas.

In the above context, the Government of India appointed the National Commission on Agriculture (NCA) on 29 August 1970. NCA submitted its final report in January 1976 in fifteen parts consisting of sixty-nine chapters. It also submitted in the course of its deliberations twenty-four interim reports. In addition, sixteen detailed reports were prepared on rainfall and cropping patterns for consideration of State authorities dealing with crop planning. Some NCA recommendations have been implemented.

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FOOD TECHNOLOGY

PROCESSING and preservation of food-stuff for future use are as old as civilization. In India the practice obtained even among the non-Aryans long before the advent of Aryan culture. The process of salting food-stuff was prevalent among those who lived near seashores, while vegetable oil was used for the purpose by the dwellers of the hinterland.

Developments in food technology during the period from 1800 to 1947 took place due to two factors. Firstly, instead of preserving food by traditional methods mainly for domestic consumption, greater emphasis came to be laid gradually on its processing for sale in the markets. Secondly, increasing contact with western food habits and food preferences generated a demand for food-stuffs for the manufacture of which the technical know-how had to be obtained from western countries.

Cereal: Rice being one of the most important cereals produced and consumed in India, its processing received attention from very early days. The practice of milling paddy is as old as cultivation and reference to it is found even in the Vedas. Different types of manually operated milling equipment for shelling and polishing of rice have been in use in India for centuries. The increasing demand for rice and exposure to mechanical operations introduced by the British accelerated the development of rice-milling technology in two areas: innovations to render hand-pounding implements more productive with reduced labour and introduction of mechanical rice mills of improved design, greater efficiency, better turnover, and higher output.

A number of traditional implements are in use in different parts of India for hand-pounding of rice. They are pestle and mortar; wooden, stone, or clay 'chakkis'; and 'denki'. The 'chakkis' comprise two discs, placed one above the other. The lower disc is kept stationary while the upper one is rotated in a horizontal plane. Paddy to be milled is fed through a hole in the upper disc and rice comes out through the gap between the two discs. To meet the need for increased production there have been modifications of the design. One such is 'Masulipatnam chakki' which was an improvement upon the stone 'chakki'. In this machine the 'chakki' is rotated at a high speed by a two-toothed pinion arrangement. The handle of the machine is rotated in a vertical plane by two men. It is a combined husking and winnowing machine, and can dehusk eight quintals of paddy in eight hours.

The pestle and mortar have been used in homes and in cottage industry

for husking paddy and polishing rice. Different designs of the equipment are in use in various parts of the country. The mortar, about 20 cm. in depth and with a diameter of 150 cm., is made of stone or wood. The pestle is a heavy wooden rod of 1·5 to 2 metres in length. It is fitted with an iron hub at one end and a ring at the other for being used for husking or polishing as required.

'Denki' is a manually operated mortar and pestle. The pestle is fixed to the end of a wooden beam which is so positioned that it swings about a horizontal axis. As the worker treads on the end opposite tc that with the pestle, the latter is raised about one metre. By suddenly releasing the pressure at the other end the pestle is allowed to drop in force for dehusking the paddy in the mortar. The position of the axis around which the beam swings determines the force transmitted to the pestle. Initially, the position of the beam used to be determined by the rule of thumb. Later, 'denkis' came to be designed with the positioning of the beam in such a way that the centre of oscillation coincides with the centre of percussion, helping the transmission of the maximum amount of force to the pestle. This also helps avoid unnecessary jerks, elastic vibration, noise, and waste of energy, which are common with the improperly designed and operated 'denki'. Although the traditional paddy husking machines and rice milling equipment like the mortar and pestle, 'chakki', and 'denki' are still being used in Indian villages, being encouraged for creating employment opportunities in rural areas, the mechanization of the operations started from the early years of this century.

Use of Power: The earliest equipment using electric power and later diesel oil introduced for rice milling in India was the stone mill similar to the wheat flour grinding machine. In 1822 paddy separation equipment was invented in Germany and by the year 1914 a number of rice milling machines of German make were introduced in India. In 1917 an Indian engineer constructed the first sheller type rice milling machine without any foreign technical help or collaboration.

Later, the Engleberg hullers operated by oil or steam engine or by electrical power were introduced. Those were relatively small units with a through-put capacity of 100 to 150 kg. per hour. Bigger mills of one to two tons per hour capacity with three to four hullers were introduced in subsequent years in many parts of India. These hullers combined the job of dehusking and polishing. Hence husk, bran, and broken rice got mixed together and their separation was difficult. Besides, the percentage of broken rice also was high.

Centrifugal shellers for rice milling were introduced in India later. In this machine the paddy grains are subjected to centrifugal forces by means of impellers rotating at 2,500 to 3,000 RPM which makes it possible to create an impact force sufficient to shell the paddy grains. It has a separate polisher for polishing the grains. As a further development in rice milling, under-runner

disc shellers were introduced. The basic machine consists of two discs with the inner faces lined with energy, the bottom one rotating and the other stationary. The efficiency of dehusking in this machine is better than that of the huller in the lower breakage and higher yield of rice. Modernization of rice mills with improved method and equipment for parboiling and hulling and utilization of by-products such as rice-bran for oil recovery had to wait till a definite policy to improve the technical operation and economics of rice milling was decided upon by the Government.

The process of parboiling paddy for dehusking was perhaps first discovered in India. Parboiled rice is popular particularly in eastern and some parts of southern India. The chief merits of parboiled rice are its higher nutritive value, greater resistance to attack by insects, and higher recovery. Recent scientific investigations have shown that parboiled rice is richer in vitamins and protein content than rice milled only after sun-drying. It is of particular importance for people whose daily food intake consists mainly of rice and is otherwise generally poor in nutrients like vitamins and proteins. Parboiling of paddy, initially started as a cottage industry, is now an important manufacturing operation without any basic change in the essentials of the process.

In the milling of wheat for the manufacture of wheat flour the age-old millstones gave way to roller-mills in larger production units in the late nineteenth century. By 1947 the flour-milling industry had been modernized to a great extent with advanced technology. But progress in the making of wheat products like leavened bread even up to 1947 was not such as to bring the industry close to western standards. Introduced in the middle of the nineteenth century, the production of leavened bread and biscuits was mainly confined to small-scale units without proper technical supervision and sanitation control. The quality was usually poor although improvements were noticed in later years. Good manufacturing standards with modern machineries and strict control over sanitation were introduced in a few establishments in the cities of Calcutta and Bombay in the beginning of this century. There have been steady growth in the demand for leavened bread and improvement in its quality since then. After independence the Government took an active part in improving the food processing industry as part of an overall policy, and India can now claim to have some of the most modern bakeries in the public sector. Biscuit-making, on the other hand, did have a better start. A few units grew up as the subsidiary of a reputed manufacturing concern of the U.K., making for the production of good quality biscuits. Although several small units came up in due course, the major portion of the turnover of biscuits was accounted for by the larger units with technological resources.

Milk and Milk Products: Milk has been a staple food for Indians from very ancient days. The chemical components of milk render it susceptible to rapid

decomposition calling for methods of its preservation in the natural form. Due to limited facilities being available and to restricted demand, mainly because of the cost involved, the preservation of fluid milk by modern scientific methods was commercially practised only in the cities like Bombay and Calcutta on a small scale till the 1950s. Indigenous methods for processing milk have been in use for a long time. These developed considerably with the inprovement of transport and communication systems. The resultant food items may be classified as unfermented milk products (e.g. dehydrated milk or *khoyā*, casein or *chānā*, and milk-based sweets); fermented milk products (e.g. curd); and products from milk fat like butter and ghee.

The preparation of *khoyā*, which accounts for most of the milk not consumed as a drink, is based on the indigenous method of controlled evaporation through heating without affecting its food value. Evaporation is done in a round-bottomed shallow iron pan over steady fire at a fairly high temperature. A specially-designed scraper is used for continuous stirring. *Khoyā* contributes significantly not only towards preventing the waste of a valuable food material but also towards reducing economic loss to rural producers of milk. It is a principal ingredient of many milk-based sweets.

Chānā is another milk product prepared by precipitating casein from boiling milk by adding lemon juice or whey from earlier batches of preparation. Lumps of casein containing the milk fat precipitate when acid is added to milk. The casein lumps are separated from the whey by filtering through a piece of coarse cloth. The remaining whey embedded in casein lumps is removed by squeezing. *Chānā* is used in milk-based confectionery, particularly popular in eastern India, and its production has grown into an industry competing with various dairy products.

Formed by chemical fermentation of milk, curd is a very popular food item in India. It is a weak gel with a smooth and glossy surface. Curd is prepared from both whole and skimmed milk. It is an intermediate product in the small-scale manufacture of butter and ghee. Even though preparation of curd is an age-old practice in India, understanding of the process involved, and its scientific control had to await precise knowledge of the work of microbes. Curd is prepared in individual households by treating boiled milk with a little curd from an earlier preparation.

Cultured starter organisms are used in the commercial production of curd. In the early thirties of this century, modified varieties of curd with the addition of colouring matter (caramel etc.), synthetic flavour, and thickeners appeared in the market. Since the Indian food laws did not permit such products to be sold as curd they were given different trade names.

Ghee is a unique milk product highly popular in India. Technically, it is only clarified butter fat obtained from milk. Ghee, which contains only traces

of water and is free from lactose and protein, is stable against microbial attack. This was probably the reason for its preparation from easily decomposable fluid milk. The demand for ghee increased with the growth of population, acceleration in urbanization, and improved communication between population centres and the hinterland. With the expansion of market, tin containers have replaced earthenwares for packaging of ghee. Quality control of ghee is difficult due to decentralized production. Nevertheless, ghee grading has been introduced in India under the Agriculture Produce (Grading and Marketing) Act of 1937 through the 'Agmark' scheme.

Application of modern technology in dairy started with the introduction of cream separator in the later part of the nineteenth century. This was followed by the establishment of creameries in cities like Bombay and Calcutta to produce butter and cream. Hand-operated cream separators were taken to rural areas by an enterprising villager in Gujarat, thereby boosting the development of dairy industry in these areas. In 1910-11, while there was good market for cream, the defatted milk left as residue had no demand and villagers found it difficult to dispose of the stock as even throwing it away caused a kind of pollution problem. About this time a German specialist (Kollar) saw the possibility of producing casein from defatted milk resulting from the separation of cream. He collected the defatted milk from farmers and started a unit for the production of casein. The product was mainly for export to Germany. Initially, Kollar paid one paisa for (1/64th of a rupee) for every 60 kg. and later raised the price to one paisa for every 40 kg. of defatted milk. Although he tried to keep the process of making casein out of defatted milk a secret, an assistant manager of the factory found it out and started a factory of his own. Later, other units were opened and production of casein became a remunerative venture for the milk producers.

The requirement of bacteria-free milk and milk products for the British army in India led to the establishment of milk-processing units in cantonment areas. In 1915 Pestonji Adelji Polson set up a dairy in Bombay and a number of cream separators in Kaira district of Gujarat to produce butter in order to meet the large demand during World War I (1914-18). A few years later, in 1929, he started a well-equipped modern plant, Polson Dairy, at Anand, which was formally inaugurated by the then Governor of Bombay on 3 January 1930. With the outbreak of World War II in 1939 the demand for butter rose enormously. At the same time there was acute shortage of milk in the city of Bombay. In November 1946 the Government of Bombay entered into an arrangement with Polsons Limited for transportation of milk from Anand to Bombay. Despatch of milk and milk products outside Kaira district without permission from the Government was banned. Polsons Limited was also given the sole right of purchase of milk in Anand and fourteen

villages around it. This went against the interest of the milk producers who were compelled to sell milk to a monopoly purchaser at a dictated price very much lower than the prevailing market price in Bombay. Sardar Vallabhbhai Patel spearheaded an agitation by farmers against the order which was revoked. He then organized the farmers into a co-operative, Kaira District Co-operative Milk Producers' Union Ltd., which was registered on 18 December 1946. In the course of time it has flourished into one of the foremost milk producers' co-operatives in the world, not only in respect of processing and distributing fluid milk but also in manufacturing products like butter, cheese, and dried milk powder and baby food.

Fruits and Vegetables: Preservation of fruits and vegetables by sun-drying or salting and/or soaking in oil has been a traditional practice in India. Pickles prepared from salted green mango slices, lemon, tamarind, olive, onion, etc. are common. A number of units manufacturing mango pickles grew up during the eighties of the last century and a flourishing export trade developed. Other types of pickles were also taken up for manufacture on commercial scale. The industry expanded steadily, although at a rather slow pace. Production of candied vegetables and fruits (*morabbā*) also made good progress during the same period.

Fruit and vegetable preservation, particularly in the canned and dehydrated form, grew into an industry during World War I when the import of canned and bottled fruits ceased. This provided a fillip to the manufacture of such products in India. A number of canning and bottling plants were established to produce fruit jam, jelly, marmalade, sauce, squash and cordial, etc. Fruits, vegetables, and fish were also canned. With the end of World War I, while the demand for such products dropped abruptly, the import of jam, jelly, etc. was resumed. As a result, most of the local plants closed down. World War II helped revive the industry which suffered a set-back again following its end. But a sizable home market sustaining the industry had already been built up. In the meantime, the Fruit Products Control Order promulgated in 1943 ensured that the products were manufactured under hygienic conditions and were in keeping with the standards of quality prescribed by the Order. Dehydration of vegetables and meat by hot air drying in dehydration tunnels was carried out extensively during World War II for army rations. But such products had very limited civilian market and the industry languished after the cessation of hostilities. There has been a partial revival recently after a number of years.

Fish: Preservation of fish for off-season consumption has been practised in India for a pretty long time. Sun-drying and salt-curing were the usual techniques. Export of dried and cured fish by India to the neighbouring countries has also been on record for centuries. Limited modernization of the

technique of salt-curing with the application of scientific principles was introduced in the erstwhile Madras Province in the twenties of this century. Proper curing techniques with quality control on salt and fish were formulated and more frictional and hygienic curing yards were established.

PROGRESS AFTER INDEPENDENCE

All-round economic progress in the country under the successive five-years plans after independence has brought about enormous changes in the food habits of the people. Processed food is more popular today than it was three or four decades ago. Growing urbanization has led to the development of food processing on scientific lines in order to cope with the demand of the city areas. This also makes for better utilization of agricultural products through different seasons and over various regions of the country.

Independence, however, brought in its train many difficult problems for India. One of the seemingly intractable amongst these was the problem of providing her large and growing population with food adequate in quantity and nourishing in quality. Against the background of food shortage in the country, loss of food materials due to spoilage was large. Hence along with the steps to increase production were taken measures to reduce losses to a technologically and economically justifiable minimum. New sources of food were also to be found to augment the available supply. To meet the problem a two-pronged attack was initiated: development of food industries and creation of facilities for research. The Central Food Technological Research Institute was established by the Government of India in 1950 to identify the problems of post-harvest food technology through research and development and to disseminate the knowledge to the people. Various steps taken to process and conserve food led to rapid development of the food industry in the country.

Rice-milling: The Government of India adopted in 1950 a phased programme of modernization of rice processing and milling with a view to achieving the twin objectives of having maximum yield of marketable rice and ensuring minimum processing losses. Since the use of huller for milling of rice results in additional 6 to 8 per cent loss in the yield, the Government of India imposed a ban on rice-milling by smaller huller machines. However, 'home pounding' was encouraged to prevent loss of existing employment opportunities and to create further employment avenues in rural areas, as it was observed that a small huller mill displaced forty persons and a rice mill about 500 persons. In 1964 a programme of introducing modern techniques in milling of rice was initiated. Seven modern rice mills were imported and installed in pursuance of this programme between 1964 and 1968. The main features of the modern rice mill are the provisions for mechanical paddy

cleaners, dryer for paddy, rubber roll sheller, separator for removing brokens (rice) from bran, and parboiling equipment if parboiled rice was to be produced. A number of modern rice mills have been installed since then with plants manufactured indigenously with foreign collaboration in some cases.

Improvement in the process of parboiling of paddy engaged simultaneous attention of the scientists and technologists. Intensive studies undertaken by them led to a better understanding of the parboiling process and development of improved techniques which not only reduced the period of soaking from twenty-four hours to less than four hours but also produced rice of a better quality in both colour and flavour. Methods and equipment for continuous parboiling and mechanical drying of parboiled paddy were also developed. The rice mills producing parboiled rice have generally switched over to the improved process and equipment developed indigenously.

Milk: Due to the importance of milk as a nutritive supplementary food for the people, particularly for the vegetarians, and the role of dairy in rural economy as an additional source of income, dairy sciences and technology involving processing and preservation of milk and of milk products got special attention from the country's economic planners. Development programmes envisage setting up liquid milk plants for the supply of milk to large consuming centres with a population of more than one hundred thousand, creameries for making butter and skimmed milk, and milk products factories for producing items like baby food, milk powder (whole and skimmed), condensed milk, table butter, and cheese. An ambitious project under the name of 'operation flood' was initiated in July 1972 to obtain a commanding share in milk marketing in the four major cities of Bombay, Calcutta, Delhi, and Madras and to speed up dairy development by increasing milk production and processing in rural areas which supply milk to the cities. Although the liquid milk plants established under the project depended on imported milk powder and butter oil to be combined into fluid milk, the long-term object was the encouragement of milk production in the country not only to replace the production of combined milk at these plants but also to achieve self-sufficiency in the country in all milk products of commercial importance.

An assured good return from the milk produced, which can only encourage the farmers to produce more milk, is tied up with many problems of procurement, transport, and processing for marketing as the principal consuming areas, the cities and the towns, are away from the producing centres. The problem of steady supply to consumers is further aggravated by the seasonal variation in the milk supply marked by 'flush season' and 'lean season'. The milk supply system in the country had to be linked with milk collection-cum-chilling centres and feeder/balancing plants including milk processing plants. Milk collection-cum-chilling centres obtain milk from the farmers and chill

it for transport. At the feeder plant milk is chilled/pasteurized in bulk for despatch to the city distribution centres. The function of the balancing plant is to balance the year-round supply of milk to the cities through 'lean' and 'flush' seasons and to conserve the surplus, if any, in the form of milk products.

Research and development studies for efficient and economic utilization of milk undertaken by institutions like the Central Food Technological Research Institute, Mysore, and the Central Dairy Research Institute, Karnal, succeeded in commercial production of baby food, dry milk powder, and cheese from buffalo milk, which accounts for the major portion of milk supply in the country. This milk had not been used before in the commercial manufacture of the above-mentioned products. India, earlier an importer of all her requirement of baby food, thus became self-sufficient in this product. The production of baby food, milk powder (whole and skimmed), and condensed milk which were practically nil in 1947 came up to 11,174; 13,900; and 6,000 tonnes respectively in 1974. The production of milk powder, however, has not been commensurate with the requirement mainly because of the limited supply of surplus fluid milk.

Fruits and Vegetables: Development of horticulture for increasing the production of fruits and vegetables to meet the nutritional requirements of the people, to generate additional income in rural areas, and to increase export earnings has an important place in the overall plans for agricultural development in the country. The perishable nature of fresh fruits and vegetables and spoilage loss up to 50 per cent in some cases called for effective methods of conservation. Construction of suitable cold storages for conservation of fresh fruits and vegetables was emphasized. These cold storages have not only helped reducing wastage in normal times to a large extent and losses during gluts but also prevented violent price fluctuations experienced before, particularly in the case of produces like potato, apples, and citrus fruits. Due to the different incentives including conservation facilities offered, the country now produces annually about fourteen million tonnes of fruits and ten million tonnes of vegetables, besides nine million tonnes of potato.

The production of canned and dehydrated fruits and vegetables and different fruit products has also helped in better utilization of the crop and in increasing export earnings. In 1982 there were 218 large-scale and 402 small-scale factories, besides home manufacturing units for preserved food and vegetables and their products. They produced 96,500 tonnes of fruits and vegetable products excluding sweetened beverages and 90,299 tonnes of fruit-based products worth Rs 66·5 million and Rs 60·7 million respectively. The export of these products (mango, pineapple, brined green mango slices, dehydrated onion and garlic) rose to 29,547 tonnes valued at Rs 218 million.

Fish: There has been marked development in fishery technology in the post-1947 era. India's coastline of about 6,600 km. offers wide access to the sea for exploitation of the marine fisheries. However, before 1947 fishing in the seas was restricted to near-shore regions and the haul was poor because unsuitable and inefficient fishing boats and manually operated gear were only used. Whatever was landed used to be mostly dried in the sun or pickled in brine in the absence of the facilities for better methods of preservation. Because of the poor quality, the products could not fetch a good price and the fishermen continued to live in abject poverty. The country had also a large potential in ponds, lakes, rivers, canal systems, and coastal swamps for the development of inland and estuarine fisheries which had not been commercially exploited to any great extent.

The development of marine fish resources was planned through mechanization of the traditional indigenous fishing boats and introduction of small new mechanized ones for inshore and larger ones for offshore fishing. In addition to a large number of traditional boats being mechanized, 19,450 trawlers and other marine fishing boats at present operate from the Indian coast. As a result of their sustained effort the haul of marine fish in India rose to 1·49 million tonnes in 1982.

India is a traditional exporter of sun-dried and pickled fish to Ceylon (Sri Lanka) and Burma and some other countries. But those were exports in low value products. The export of more sophisticated products like canned, frozen shrimp and fish to industrially and economically advanced countries has opened a new avenue and given a great fillip to the fishery industries in India. The value of exported fish, mainly shrimp, and fishery products rose from about Rs 50 million in 1954 to Rs 3,420 million in 1982. The traditional export of dried and pickled fish was mostly replaced by canned and frozen shrimps and fish, frozen shrimp comprising about 72·7 per cent of the quantity and 87·9 per cent of the value for the exported marine products. The fish-freezing industry has had a rapid growth to meet the export demand. The number of marine fish-freezing and canning plants, which were practically non-existent in 1954, rose quite notably in 1982—the former accounting for 322 units with a total capacity of 1,486 tonnes per day and the latter for 69 units with a capacity of 249 tonnes per day.

While exploitation of the marine fish resources has received particular attention, significant progress has also been recorded in the development of inland fisheries through the application of modern technologies. One of the bottle-necks, availability of fish seeds, has been tackled by the production of fish seeds by induced breeding and modern hatchery practices. The required research and development support for the fishery industry in India is being given by the Central Marine Fisheries Research Institute, the Central Inland

Fisheries Research Station (established in 1949), and the Central Institute of Fisheries Technology set up in 1957.

Protein-rich and Enérgy Food: The poor nutritional level in the country has called for urgent remedial measures, particularly in respect of the vulnerable groups in the population, i.e. children and pregnant and nursing mothers. It was necessary to develop and produce on a fairly large scale food formulations which would be cheaper but would meet the nutritional requirement of the target groups in the population. The Central Food Technological Research Institute (CFTRI), Mysore, developed a number of protein-rich foods based on the cheaper sources of vegetable protein like oil cakes. The Government of India set up the Food and Nutrition Board in 1964. The Board with the technical help from CFTRI arranged to produce a number of food compositions to serve as weaning food for babies, food for school-going children, as well as nutritionally enriched or fortified common items of daily diet. Chief among the food compositions developed and produced in significant quantities are (1) 'balhar'—a product made from purified oil cakes, lentils and legumes with added minerals and vitamins, used largely for feeding schoolchildren; (2) 'poustik atta'—whole wheat flour mixed with purified groundnut flour for general consumption by economically backward sections of the population; (3) 'miltone'—a fluid milk substitute based mainly on cow/buffalo milk (40 per cent) and solubilized groundnut (nearly 60 per cent) products. About 40,000 tonnes of 'balhar' are being produced annually. 'Miltone' is being produced and marketed by different centres in India and 2·6 million litres of 'miltone' were produced in 1982.

Low-cost, ready-to-eat nutritious food, given the general name of energy food, developed from locally available raw materials like wheat flour, groundnut flour, Bengal gram flour, and jaggery, is being used in special nutrition programmes mainly for children. Different varieties of energy food are now being produced by both Government and private units.

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ATOMIC ENERGY IN INDIA: AN HISTORICAL PERSPECTIVE

INTRODUCTION

THE culture of a nation generally refers to the intellectual wealth, atmosphere, and the stage of development of its people. It is a continuously evolving, dynamic process comprising various experiences, training, and action. Music, dance, drama, literature, and other forms of artistic activities are generally taken for granted to constitute cultural heritage. On the other hand, scientific pursuits, industry, technology, etc. are not generally appreciated to form part of culture. However, it is now well recognized that scientific and technological innovations change and contribute to culture. Even in fine arts like dance, drama, and music, science and technology have introduced many devices for better performance and projection to eager audiences simultaneously and concurrently. The enormous amount of leisure provided to the community in general by mechanization of production facilities in industry and agriculture has a bearing on the cultural pursuits of its people. Do we have a cultural heritage in atomic energy? I believe we have one. How much of it will we pass on to the future? What is the present status? These are some of the questions we shall examine in this article. As one who has more faith in the future and has deep roots in the present, I would only be cursory in elucidating what we inherited from the past.

The introduction of western science in India is very recent. In the first half of the British rule and even in the first half of the nineteenth century, the rulers were content to have the natives only as technical assistants to their scientific explorers in this country. A large number of Britishers came to this country to explore the resources, the land, the forests, and the like purely from the point of economic gains to the overlords. Technical surveys like the botanical survey, the geological survey, etc. and setting up of departments like the meteorological department were purely directed towards resource survey and later exploitation for supplying raw materials to feed the industries in Britain. The British Government, while interested in creating an army of 'babus'—the clerical staff—to assist in the day-to-day administration of the country, were most reluctant to have Indians in the top echelon of any activity. The educational pattern followed a plan towards this end in view. Study of liberal arts, languages, mathematics, etc. were allowed while technical subjects like the sciences, engineering, etc. were not encouraged. Perhaps a feeling of suspicion and a

sense of secrecy regarding the outcome of the surveys prevented them from allowing the natives to have knowledge of the methods of survey and experimental scientific activities or tó have engineering acumen. Medicine, however, was not neglected, because it helped them to find personnel to serve the sick military or civilian personnel of the Government. Even in this atmosphere, there were a few bright Indians who realized the importance of science and scientific investigations, and it is their zeal which resulted in the setting up of a few science and engineering colleges here and there by the middle of the last century with the support of a handful of sympathetic Britishers. We may consider this as the beginning of the study of western science in this country. European literature on science, industry, and technology; chemicals; and various forms of research equipment slowly found their way into the country. India had missed joining the other European countries in the industrial revolution of the eighteenth century and was late in picking up a few strands of technological development. A proposal to set up universities and professorships in various branches of science, civil engineering, law, and languages was mooted in the 1850s. But the universities were to remain as examining bodies and not teaching institutions. By 1900, there were five universities and about a hundred colleges in the entire country which included the undivided subcontinent. By the 1920s it was recognized that the universities must become centres of teaching and research. There were a few determined efforts by persons like Mahendra Lal Sircar to set up scientific institutions or elite bodies in the country on the British pattern. The Indian Association for Cultivation of Science took shape in 1876. The history of the first half of this century is one that we are all aware of. This period is marked by hectic activity to achieve political independence and a keen sense to participate in all phases of the country's development. This period also saw the emergence of leaders in scientific pursuits and excellence like J. C. Bose, P. C. Ray, S. N. Bose, Meghnad Saha, C. V. Raman, H. J. Bhabha, Birbal Sahni, and Bhatnagar. Ramanujan, the illustrious mathematician, was like a fleeting meteorite in the firmament of Indian scientific activity. At the time of our achieving political independence in 1947, there were about twenty universities in all, most of them being teaching and examining institutions by that time. One may summarize the situation till 1947 as a state of almost zero growth. Science and technology known at that time in the country was all borrowed rather to cater for the necessities of the empire than to fulfil the desires and demands of our people.

CONCEPTION OF NUCLEAR ENERGY PROGRAMME

The Nuclear Energy Programme in the country originated from the conviction, determination, and drive of a dedicated individual Homi Jehangir Bhabha. Bhabha had part of his education at Cambridge in England in the

thirties, wherein such stalwarts of the early nuclear science like Lord Rutherford, Sir John Cockroft, and many others had contributed richly to the physics of their times. Bhabha began his career as an engineer; later on, his interests switched to mathematics, theoretical physics, and experimental cosmic ray physics as in the case of Pauli, Fermi, and Kramers in Europe. His contributions to the world of physics were well known and he had been elected as a Fellow of the Royal Society in 1941 at the age of thirty-one. Bhabha returned to India in the early forties and organized a small research group at the Indian Institute of Science, Bangalore, for experiments in cosmic rays and research in theoretical physics. He kept himself abreast with the latest developments in nuclear physics and other allied subjects. With the beginning of the second World War in 1939, scientists in various parts of the world had to either give up their countries of origin and migrate to other countries or give up research activities in their fields of interest. Fission process, which we shall discuss later, had been discovered towards the end of the thirties by the efforts of Otto Hahn and independently by Lise Meitner and O. R. Frisch in Germany. It was soon realized that further exploration and exploitation of fission would give man a new source of large amounts of energy. However, the military dictates of the time brought most of the research in the field under a shroud of secrecy. The war came to an end in the middle of 1945 with the explosion of atom bomb over Japan.

Endowed with a rare imagination and great vision, Bhabha thought even before the explosion of the atom bomb—and consequent demonstration of uncontrolled release of energy—that the atom possessed energy that was controllable. In an era when communication regarding exploitation of atomic energy was restricted amongst a few scientists in the United States, Britain, and Canada, he could foresee the importance of peaceful uses of the atom independently. In a now celebrated letter dated 12 March 1944, Bhabha wrote to the trustees of the Sir Dorabji Tata Trust, Bombay, proposing the establishment of an institute for fundamental research in the fields of physics and mathematics. It was the Dorabji Tata Trust that had supported him in his work at Bangalore and to it he turned again. In this famous letter he went on to state that it was 'absolutely in the interest of India to have a vigorous school of research in fundamental physics, for such a school forms the spearhead of research, not only in less advanced branches of physics but also in problems of immediate practical application in industry. If much of the applied research done in India today is disappointing or of inferior quality, it is entirely due to the absence of a sufficient number of pure research workers who would set a standard of good research. . . . When Nuclear Energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand. . . .'

In response to the proposal mentioned above, the Tata Institute of Fundamental Research was founded in 1945 as a joint venture of Sir Dorabji Tata Trust and the then Government of Bombay. The Institute had an humble beginning with a handful of people in small rented premises at Peddar Road, Bombay. For a number of years it functioned at the Old Yatch Club premises—this continues to house the headquarters of the Atomic Energy Commission even to this day—and at the barracks off the Colaba seashore. The Institute moved over into its own beautifully proportioned buildings built entirely by Bhabha's own mind and heart stage by stage later on. Unlike the laboratories of the Council of Scientific and Industrial Research, the Institute did not have a set pattern. Bhabha considered it imperative to build the organization around chosen people rather than draw an organization plan or a chart first and then fill in the vacancies. Furthermore, he conceived of the Institute as an embryo from which he hoped to build up in the course of time a school of physics comparable to the best anywhere. True to his hopes and ambitions, the Institute has turned out to be one of the best known research centres for physics and mathematics in the world.

Though himself a theoretical physicist, Bhabha gave considerable support to all experimental techniques at this Institute and even in this he emphasized the need to develop indigenous techniques and know-how. There were under construction as early as in 1952 a cyclotron, a Van-de-Graaff machine, a linear accelerator, a mass spectrometer, beta ray spectrometers, cloud chambers, multi-channel analysers, nuclear detectors, and a host of other electronic instruments needed to support nuclear research. Considering the funds available, it would have been quite easy, as pointed out by P. K. Iyengar, to have bought a cyclotron and a lot of electronics to start fundamental research in nuclear physics. Bhabha deliberately limited the purchase of equipment from abroad emphasizing the need to develop technology of all kinds required for nuclear research. This approach was in sharp contrast with organized pure research at that time in the universities in the fields of spectroscopy and crystallography where investigations were carried out on new samples of crystals and molecules by well-established techniques using standard imported equipment.

Atomic Energy Act: The Atomic Energy Act was passed on 15 April 1948 and the Atomic Energy Commission was set up in August 1948 with Bhabha as its Chairman to formulate policies and programmes in order that India might become one among the leading nations in this new technology. Among the tasks assigned to the Commission were survey of the country for minerals of interest for a successful atomic energy programme, training of necessary technical and scientific personnel to carry out development of nuclear technology, and encouraging research in its own laboratories and other institutions.

BHABHA ATOMIC RESEARCH CENTRE (BARC)

Bhabha had the distinction of concurrently holding the offices of the Director as well as Professor of Theoretical Physics at Tata Institute of Fundamental Research, and Chairman of the Atomic Energy Commission. Later he became also the Secretary to the Ministry of Atomic Energy and held this office till his untimely death in January 1966. This gave him a unique position. As Chairman of the Commission and Secretary to the Ministry, he had both the policy-making and executive powers. At the Tata Institute, he had already a band of enthusiastic and bright scientists working with him in various research areas. Perhaps, if a single antecedent has to be picked out to explain the ultimate success his programmes achieved, it is this blend of planning and implementing authority which was reposed in him.

To implement the aims of the Commission a new strategy had to be adopted. There was need to build up teams of chemists, metallurgists, biologists, physicists, nuclear engineers, chemical engineers, and others of various disciplines. Bhabha used the facilities of the Tata Institute to form the nucleus for evolving such a group in the fields of nuclear physics, chemistry, metallurgy, and electronics. Biological and medical activities of the programme got started from the Indian Cancer Research Centre and Tata Memorial Hospital, Bombay. These two bodies now form one unit, the Tata Memorial Centre. The Tata Institute of Fundamental Research and the Tata Memorial Centre are rightly called the 'cradles of India's atomic energy programme'.

The Atomic Energy Commission decided in January 1954 that a separate institution called the Atomic Energy Establishment should be set up at Trombay near Bombay for research in and development of peaceful uses of atomic energy. The Trombay establishment covered well over 5 sq. miles and was flanked on one side by the Trombay hills and on the other by the backwaters of the Thana creek. The site is picturesquely situated facing the Elephanta Caves on the northern side. The establishment was formally inaugurated by Nehru in January 1957. The saga of atomic energy in India is the narration of the activities and growth of this Centre renamed Bhabha Atomic Research Centre (BARC) in 1967 to perpetuate the memory of the great scientist.

SCIENTIFIC POLICY RESOLUTION

Development of nuclear energy in the country depends on a new technology unknown to the country before. One had to create centres wherein this new technology could be generated and adopted for use on an industrial scale. It has been the policy of the Government to foster and support all attempts and activities towards application of new scientific techniques which

can make up for the deficiency in natural resources and reduce demands on capital. In keeping with this policy, the Government of India decided, on the basis of experience, that the aims of the country's scientific policy on a continuing basis would be

(i) to foster, promote, and sustain, by all appropriate means, the cultivation of science, and scientific research in all its aspects—pure, applied, and educational;

(ii) to ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognize their work as an important component of the strength of the nation;

(iii) to encourage and initiate, with all possible speed, programmes for the training of scientific and technical personnel on a scale adequate to fulfil the country's needs in science and education, agriculture and industry, and defence;

(iv) to ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity;

(v) to encourage individual initiative for the acquisition and dissemination of knowledge, and for the discovery of new knowledge in an atmosphere of academic freedom;

(vi) and in general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

The Nuclear Energy Programme in the country originated a decade before this policy emerged and it is gratifying to note that this programme fulfils all the aims of the policy in action. By adopting the scientific policy resolution, the Government pledged support for all similar scientific and technological developments.

SOURCES OF ENERGY

Nature provides a variety of sources of energy. Some of these have been tapped and some remain untapped. Among these we may mention (i) firewood, dung, and wastes, (ii) solar energy, (iii) energy contained in winds, (iv) tidal energy from the ocean, (v) geothermal energy stored in the interior of the earth, (vi) hydro-electric power, (vii) fossil energy in the forms of coal and natural gas, and (viii) nuclear energy. Of these, the first has been known to man for ages. In India the next four remain almost untapped. Hydro-electric power has been tapped wherever feasible through several multipurpose river valley schemes. Unfortunately, many of the rivers in India are not perennial, being dependent on the monsoon. Hence there have been some suggestions to form a river grid covering the entire country so that excess water from one region could be made available to areas where there is scarcity of water.

This scheme is popularly referred to as the Ganga-Cauvery Project. Although the suggestion is interesting, care should be exercised in examining the proposal on the basis of technical possibility, feasibility, economics, and time needed for implementation. Fossil energy has been the main source of power that India has exploited so far on a commercial scale. But it is being realized that the stock of fossil fuel is not inexhaustible, and, in fact, there is a genuine fear that at the present growth rate of consumption most of it will be exhausted within another hundred years or so. In the sphere of conventional energy production India is among the first five countries of the world. Due to the high density of population, however, in the matter of per capita energy consumption India's place is nowhere in the top bracket. With economic development the demand for energy is on the increase. The pressure on the coal reserves of the country may be gauged from the fact that one kg. of coal is needed to produce one kw. of power. That is to say, a power station generating 200 megawatts consumes nearly 2,000 tonnes of coal per day. Hence there is need for developing other energy resources and using them on an efficient and economical scale in a big way. Nuclear or atomic energy provides one such alternative source.

WHAT IS NUCLEAR ENERGY ?

All matter is made up of a few basic elements and these in turn are made up of what are known as atoms. The atom is the smallest building block, one may say, which possesses all characteristics of the element. It has a size of the order of 10^{-8} cm. and a weight of nearly 10^{-23} to 10^{-21} gm. Substances like hydrogen, copper, lead, etc. are all made of these atoms. However, some of the atoms of an element are lighter or heavier than the typical atom. Hydrogen, for example, exists with three types of atoms whose weights are in the ratio of nearly 1:2:3. The reason for this is to be found in the internal structure of the atom. The atom has a small charged core in its centre called the nucleus—of size nearly 10^{-13} cm. consisting of smaller particles referred to as protons and neutrons—around which one finds an electronic cloud. The proton and the neutron are the elementary nuclear particles having similar masses, nearly that of the hydrogen atom itself but possessing different electrical charges. The proton has a unit positive charge whereas the neutron is electrically neutral. The different species of hydrogen atoms consist of one proton but different numbers of neutrons, the three species consisting of 1 proton plus 0 neutron, 1 proton plus 1 neutron, and 1 proton plus 2 neutrons. Atoms which differ from each other in the number of neutrons but which possess the same number of protons as mentioned above are referred to as isotopes. The isotopes of hydrogen are named as hydrogen, deuterium, and tritium. Such a nomenclature to identify isotopes does not exist

for isotopes of other elements. Symbolically one represents the isotope of an element by ${}^{A}_{Z}X$ where Z is the number of the protons, A the number of protons plus neutrons, and X the symbol of the element. For example, one of the isotopes of gold is represented as ${}^{197}_{79}Au$. As one proceeds along the periodic table of elements beginning from hydrogen, one finds that the number of protons and the number of neutrons are almost equal in most of the elements of low atomic weight. As one reaches elements of larger atomic weight, one finds that they are neutron rich. The element uranium, for example, has two isotopes that occur in nature, ${}^{235}_{92}U$ and ${}^{238}_{92}U$, indicating the large number of neutrons in the nucleus, compared to the number of protons.

The neutron is, as already said, electrically neutral. A free neutron therefore can penetrate the core of the atom without much difficulty. When a neutron is added to ${}^{235}_{92}U$ or ${}^{238}_{92}U$ with sufficient energy, it creates an imbalance in the nucleus. A neutron which is in thermal equilibrium with any condensed system at room temperature possesses an energy of nearly 0·025 ev (1 ev is the unit of energy 'electron volt', normally used in nuclear physics, equivalent of $1{\cdot}6 \times 10^{-12}$ erg; 1 MeV$=10^{6}$ ev). If such a neutron enters a ${}^{235}_{92}U$ nucleus, its energy is sufficient to bring catastrophic breakdown of the nucleus itself. The nucleus breaks into two dissimilar nuclei. A few neutrons from the 'compound nucleus' also get freed. But the most interesting aspect is that the total mass of the two nuclei plus neutrons after the process does not equal the mass of the parent nucleus plus the neutron before the process got started. The 'mass defect' gets converted into kinetic energy of the two nuclei—referred to as nuclear energy (or atomic energy)—and of the neutrons. About 200 MeV of energy is liberated this way, a consequence of the famous Einstein equation $E=Mc^{2}$. Comparatively, in burning of coal or a chemical reaction a few kilocalories of energy is liberated per mole (or 10^{-2}ev per atom approximately). This shows that in this particular 'nuclear reaction' one gets an enormous amount of energy released. The entire process is referred to as fission. The fission neutrons have energies of the order of a few MeV. If these neutrons can be made use of again with ${}^{235}_{92}U$ or ${}^{238}_{92}U$, one has a rapidly multiplying chain of fission events occurring starting from a single event. The energy released thereby is uncontrollably large. For example, in the complete fission of 1 gm. of ${}^{235}_{92}U$ energy equivalent of that from detonation of 1 ton of TNT is released. The threshold neutron energy for creating such a fission event in ${}^{238}_{92}U$ is nearly 2 MeV.

The facts mentioned above have been known for about thirty-five years. The atom bomb was the first public demonstration of large-scale release of atomic energy and was used to devastate Hiroshima and Nagasaki in Japan. During the early forties, a group of physicists under the leadership of Enrico Fermi set up a nuclear reactor to control the chain reaction from a run-away

condition. Theirs was the first attempt to harness the atom for peaceful purposes. The first controlled chain-reacting pile operated at Chicago University in December 1942. But it remained a secret project till after the war.

HARNESSING THE ATOM

How does one control the run-away chain reaction? The chain reaction occurs because the neutrons, born at fission of a nucleus, find in their immediate neighbourhood atoms of the fissile material like ${}^{235}_{92}U$ and hence more fissions take place. If the fissile atoms are out of reach of the neutrons and if the neutrons get absorbed in other materials, the chain reaction can come to an end. On the other hand, if there are fissile materials available in the neighbourhood always, one event can trigger off an uncontrollable chain reaction. Hence the trick to control the chain reaction at a desirable rate is to disperse the fissile material in a non-fissile material and to control their relative composition, size, etc. so that having achieved a certain fission rate, one should keep the fission rate steady at the level without decrease or increase. This is successfully achieved in a nuclear reactor. Here one mixes the fissile material (e.g. natural uranium, uranium enriched with ${}^{235}_{92}U$ or ${}^{239}_{94}Pu$, etc.), non-absorbing materials (heavy water D_2O, light water H_2O, graphite, etc.), absorbing materials (Cd, B), etc. in a suitable geometry, composition, and size to perpetuate a self-sustaining chain reaction. Depending on the heat transfer considerations, using suitable coolants one can operate such a reactor at any desired power level from zero to hundreds of MW depending on the nature of the reactor and auxiliary facilities and the purpose to which the reactor is to be used. The coolants get heated and this heat can be suitably extracted to produce steam to run conventional generators to yield electrical energy.

TECHNICAL FALL-OUTS

Harnessing the atom needed the building of various instruments, plants, and technologies before the fruits could be derived. Electronics instrumentation, nuclear detectors, nuclear instrumentation, uranium metal extraction, uranium fuel fabrication, radiochemical techniques, fuel processing plant, and vacuum technology are some of the aspects of the work which grew slowly but steadily around small groups. The momentum generated by a 'growing science' could not be contained within the physical limitations of BARC. Today several large national ventures and public sector industries have been established once again by drawing persons specialized in various technologies carefully nurtured at Trombay. To mention a few, we have the Electronics Corporation of India Ltd., Hyderabad, the Nuclear Fuel Complex at Hyderabad, and the Uranium Corporation of India. What is

more important to realize is that the culture transferred from Trombay has transformed itself into monolithic organizations and they spread the culture in a variety of fields in their turn. Trombay continues to mother such offspring again and again and has continuous and cordial relations with them.

TRAINING PROGRAMME AT TROMBAY

Development of a new technology like atomic energy in a country like ours needs the creation of a cadre of scientific and technical personnel who are capable of executing, planning, and advising on various aspects of the national programme. Perhaps this is one interesting and important aspect of the growth of nuclear energy in India. It is important to realize that the era of nuclear technology started without sufficient back-up technology in the country in conventional aspects of technology. The necessary personnel had to be grown at home to suit our needs and demands. One way was to attract personnel from other industries, other institutions, and the like. But this process would be harmful in the long run when viewed from the national perspective, because such a process would deprive the other institutions of capable people. Hence an important decision that Bhabha took was to start a training scheme for orienting first class graduates from universities. The training school was started in 1957. Nearly 200 graduates in science and engineering from all over the country were recruited for training every year and they were taken through a broad-based programme in nuclear science and engineering, equipping them to adapt themselves to the work in any of the areas they were assigned. At the end of the training programme, the students were absorbed in various working groups where they gradually attained the maturity, knowledge, and experience required of them in bearing responsibilities in future. This method of training personnel was found to be highly rewarding since a broad base was given to each trainee and the department did not have to go looking for the personnel when a new project was planned. The training school and training programme had been under the personal care and supervision of Raja Ramanna who spared no pains to set a philosophy of training to guide the growth and nurture the institution to have a self-sustaining programme. In his view, 'the school has more than fulfilled the needs of the institution in the sense that it has not only supplied the requisite manpower, but also discipline to work in teams, so that projects can be undertaken and finished within a definite time period'.

Over the years, the training school has contributed to more than 50 per cent of the total number of scientists and engineers at BARC. In addition to such formal training, courses were also organized for specialized operations of chemical plants and the use of radio isotopes in medicine, industry, radiation safety, etc. BARC has also collaborated with a large number of neighbouring

developing countries like the Philippines, Thailand, Korea, Taiwan, and Indonesia by sharing its experience in several fields like solid state research using neutrons, reactor operations, etc. through bilateral, regional, and international agreements. Through the aforesaid training programme BARC acted as a catalyst in the spread of science and technology as a whole in the country. Other training programmes carried out by BARC are short-term courses for doctors, radio-therapists, teachers in universities, etc. in specialized areas. Symposia, seminars, and conferences organized by various divisions of BARC annually in various regions of the country in different disciplines have sustained the growth of science and have offered platforms wherein dissemination and discussion of scientific activities in progress in the country take place on a continuing basis. These cover a wide spectrum of science and technology like nuclear physics, solid state physics, chemistry, metallurgy, biology, etc.

STAGES OF DEVELOPMENT

Bhabha delineated the programme of development of atomic energy that India would have to follow. The first stage was to be reactors of natural uranium for producing power and plutonium; the second stage of reactors would use plutonium and produce the fissile isotope $^{233}_{92}U$ from $^{232}_{90}Th$ and the final stage would be $^{233}_{92}U$ reactors for breeding $^{233}_{92}U$ from $^{232}_{90}Th$ and producing power.

A swimming pool research reactor named 'Apsara' was designed and built in 1955-56. The design of the reactor and fabrication of necessary electronic control system were entirely carried out by Indian scientists and engineers. Only the fuel elements which contained enriched uranium were supplied by the United Kingdom Atomic Energy Authority. The reactor attained 'criticality' on 4 August 1956 and was the first one in Asia, two years earlier than the first reactor in China designed and built by the Soviet Union. This reactor has been extensively used for studies in neutron physics and nuclear fission investigations, in radiation chemistry, and in experiments on agriculture and biology. The reactor also began to be used for production of radioactive isotopes in the beginning of 1958. Thus, with the experience gained from the 'Apsara' reactor, scientists were fully geared to use the bigger CIRUS reactor when it went into high power operation in 1962.

At the time of building 'Apsara', plans were afoot to design a reactor suitable for engineering experiments. The Canadian Government offered to build a bigger research reactor which could accommodate such objectives in addition to being a good research facility. The CIRUS reactor at Trombay is almost a copy of the NRX reactor at Chalk River with minor modifications. It being a Canadian gift under the Colombo Plan, all parts of it came from Canada and the construction was jointly carried out with Indian engineers.

The CIRUS reactor uses natural uranium fuel, heavy water as moderator for slowing down neutrons, and ordinary water as coolant. It was decided, therefore, early in 1956 to set up a uranium metal plant and a uranium fuel fabrication facility. The first ingot of atomically pure uranium rolled out of the metal plant in 1959. Similarly, the first fuel element was produced in 1959 at BARC. Fuel element production is a tricky and difficult job in nuclear industry and the fact that fuel elements standing up to the most vigorous tests in Canada could be produced in about four years was a major landmark in our nuclear growth. It acted as a fillip to our technical personnel to undertake difficult tasks. The advantages gained by the know-how, saving of precious foreign exchange, and the low cost were the other merits of the venture. The fuel fabrication plant has since diversified its activities in producing zircalloy, nuclear-grade uranium, oxide pellets, new types of fuel bundles, etc. The techniques developed at the plant have been useful in such remote areas as the making of microwave cavities.

Steps were also taken to set up a large-scale heavy water plant at Kota in Rajasthan to cater for the needs of future power reactors. Similarly, the electronics division expanded its activities to produce not only the nuclear instruments and reactor control instruments but also other items and components. The expansion of electronics in BARC was rather impressive. Bhabha was called upon to submit a report on electronics in India in the early sixties. Thanks to his zeal and enthusiasm, an electronics plant was set up at Hyderabad under the auspices of the Department of Atomic Energy 'for the manufacture not only of the nuclear instrumentation, including that which is required for routine production and use of isotopes in hospital and industrial establishments and laboratories as also the control system of reactors, but a variety of electronic components and equipment, which BARC has been able to develop and which are required by the electronic industry generally, but are not yet produced in the country'. The plant has now come to be known as the Electronics Corporation of India Limited (ECIL).

Bhabha also considered making use of foreign collaboration just to help in a quicker take-off in the area of nuclear power. A turnkey contract was given to International General Electric to supply and erect a 400-MW nuclear power station at Tarapur near Bombay. Such a step helped bypassing building a prototype reactor which would have taken anywhere from four to six years.

The second stage of development as envisaged by Bhabha involved the use of plutonium produced in reactors of first stage in fast breeder reactors. Extraction of plutonium from burnt uranium fuel is a complicated process as it calls for handling large-scale radioactivity. Plutonium being fissile element, adequate safeguards must be taken so that 'criticality' accidents do not take place. In addition, plutonium is a highly toxic element. To understand and

develop the chemical aspects of handling plutonium, a beginning was made by setting up a small radiochemical laboratory. Secondly, a pilot plant to process 20 to 30 tons of used uranium was also set up. This fuel reprocessing plant was designed and constructed by Indian engineers under the leadership of H. N. Sethna. The experience gained in this plant, in operation since 1965, has helped in the designing of the full-scale industrial processing plant at Tarapur for power reactor fuel processing. Plans were afoot to set up similar plants at Kalpakkam also.

The main emphasis in this stage was on development of fast breeder reactors. What are fast breeder reactors? India has the largest reserves of the fertile element thorium occurring in the monazite sands of Kerala. This element cannot be used as fuel directly in any nuclear reactor. However, thorium gets converted into the fissile element $^{233}_{92}U$ by neutron absorption in a reactor. Hence, if in a reactor one has enough neutrons to spare for this conversion process, one can breed fuel in such a reactor. This means that in every fission occurring in such a reactor one must have at least two neutrons available after taking into account all losses like leakage etc.—one neutron could be used for sustaining the chain reaction and the other for breeding. This is a possibility in reactors making use of Pu as fuel and the breeding ratio, that is the number of fissile atoms produced to fissile atoms burnt, can be as high as two. Neutrons having energy of the order of 1-2 MeV are able to take part in this process quite efficiently. Hence the reactors are referred to as fast breeders.

Kalpakkam near Madras was planned to form the nucleus for all activities connected with the fast breeder reactor systems and technology. To begin with, a Fast Breeder Test Reactor (FBTR) of 15 MWe is being set up in collaboration with the *Commissariat à l'Énergie Atomique* (*CEA*), France. The reactor being built is similar to the French reactor *Rhapsodie* at Cadarache. The construction of the reactor is the responsibility of Indian engineers. The know-how for indigenous fabrication of components and equipment for the reactor is being obtained from the French industry. The FBTR when commissioned will provide experience in the designing, construction, and operation of a Pu-fuelled, liquid sodium-cooled fast reactor. Such experience will help in the development of larger commercial fast breeder reactors. Material testing and fuel testing are essential aspects of fast reactor technology. These tests can be carried out by using FBTR as an irradiation facility.

Another important landmark in the work towards the fast reactor development was the attainment of criticality of a zero energy fast critical facility on 22 May 1972 at Trombay. An experimental critical assembly consisting of plutonium oxide fuel elements with molybdenum, copper, and steel reflectors was set up at BARC under the leadership and guidance of P. K. Iyengar.

The experiments carried out so far have given valuable information concerning the reactor parameters for constructing and operating a Pulsed Fast Reactor at Kalpakkam (KPFR). KPFR itself will be used for gaining experience in the physics of fast reactors and also for a number of neutron experiments.

In the third stage of development, the aim is to decrease the dependence on plutonium-fuelled breeder reactors for they in turn depend on the production of plutonium in natural uranium-fuelled heavy water moderated reactors. This can be achieved if we have sufficient inventory of $^{233}_{92}U$ by breeding from thorium in thermal and fast breeder reactors of the first and second stages. Once this inventory is achieved, we have essentially a self-sufficient cycling to breed $^{233}_{92}U$ and to burn it for power production.

CONCLUSION

To uplift the standard of living of our people the Government, the planners, and the economists have endeavoured to give support to several activities concerned with industry and technology. However, these efforts would succeed only if the cultural aspects of activation and management involving human and organizational inputs are properly understood and suitably taken care of. It is in this spirit that one should study the growth of atomic energy in our country.

It is difficult to write a short summary of what we have mentioned earlier. We have attempted in this article in particular to trace the growth of atomic energy in India from 1947 onwards. It is a culture which is being introduced into our socio-economic system as an essentially post-independence phenomenon. Unlike a foreign body which could be easily rejected by the organic rest, this culture is slowly but steadily getting assimilated by the entire nation. The impact of the great vision of Bhabha on several spheres of activity like education, training, medical aid, research, development, technology, and industry through the introduction of atomic energy is far-reaching and all-embracing. We have tried to analyse the philosophy, planning, and growth of the new technology. Atomic energy development is development of an appropriate technology which, according to Prof. Sethna, means 'technology appropriate to our economic conditions; technology that can produce the needed goals and services most optimally; technology that can utilise our own natural and human resources effectively and technology that can become a part of the social milieu'.

The pivotal role of BARC in the proliferation of atomic research cannot be overestimated. It has turned out to be a unique institution in the country to nurture small undertakings to begin with—undertakings which later grew to be giant organizations in their own right. BARC is very much like a technical

institution in many respects developing 'knowledge and skills which are most appropriate to our needs'.

Two basic tenets that have guided the working of the Department of Atomic Energy (DAE) are appropriate choice of research projects and transfer of know-how of a technology developed under its aegis. It is this outlook which has not only saved the institutions under its fold from getting to a moribund state unlike some other institutions but also to revitalize its activities periodically. Re-assessment and re-evaluation of projects in hand on the one side and critical examination of new projects to be taken up on the other have acted as machinery to check if certain activity is relevant to our needs or not. On a smaller scale, high vacuum technology and applications of isotopes in medicine, industry, agriculture, and research are examples of technology transfer to various outside organizations. On a bigger scale, the Electronics Corporation of India Ltd., the Nuclear Fuel Complex, and the several power stations and power projects stand out as instances of notable development.

Demands on energy resources in the country are growing at more than a linear rate year after year. Questions concerning the economics of the use of fossil fuel and nuclear fuel for power production have no or very little meaning. The necessity of conservation of fossil fuel for other purposes far outweighs any such argument. Similarly, the needs of mass communication, medical aid, etc.—apart from defence needs—call for research and development in new areas. At Trombay—synonymous for centres of atomic energy in India—work along large-scale development of cryogenics, microelectronics, plasma technology, lasers, etc. will be pursued. Exploitation of our large resources of thorium will be the aim in the next two decades. Towards this end in view, research and development in areas like radiation-hardened or radiation-curable materials, fast reactor technology, nuclear enrichment plants for U^{233}, etc. will occupy the interest of many workers. The nuclear industry in the country has still remained very much with DAE. It has reached a level of self-sufficiency in many areas. The lacuna for falling short of our targets for planned growth is found to lie with the rate of growth of conventional technologies in both private and public sectors to meet the challenges of the nuclear field. Growth and acceptance of nuclear needs by other industries will help in the overall growth of several technologies to meet the hopes and aspirations of our people.

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NUCLEAR ENERGY IN INDIA : GROWTH AND PROSPECTS

ATOMIC NUCLEUS—A SOURCE OF ENERGY

THE material objects we see around us are composed of substances that are classified by scientists into elements and compounds. Hydrogen, oxygen, carbon, sodium, silver, gold, etc. are elements because they cannot be broken up into other substances by any chemical means. On the other hand, water, common salt, etc. are reckoned as compounds because water can be experimentally shown to yield hydrogen and oxygen, and common salt to yield sodium and chlorine. All these are results of observations in a chemical laboratory carried out with macroscopic quantities of the relevant substances. If a bulk quantity of any substance is divided into smaller and smaller parts and we ultimately reach microscopic dimensions, a stage comes when the microscopic unit obtained in the process still retains all the properties of the parent substance, but further subdivision of that unit yields microscopic entities with entirely different property. The smallest microscopic unit of a compound that retains its properties is called its molecule and further subdivision of the compound molecule yields the atoms of the elements of which the compound is made up.

An idea of the dimensions in the microscopic domain of atoms is very pertinent here. In our everyday life we deal with macroscopic objects whose lengths are measured in units of kilometres, metres, centimetres, millimetres, etc. depending on the actual size of the object. Imagine dividing one millimetre into ten million equal parts. Each such tiny part is called an Angstrom unit. The lengths in the atomic domain are equal to one or a few such units. One milligram of hydrogen gas contains about six hundred billion billion* atoms of hydrogen. This would convey to the reader how extremely light *one* hydrogen atom is. Of all the elements that are known in nature hydrogen has the lightest atom. Next come helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, etc. in order of increasing atomic weight. A small quantity of mercury in a glass jar or a small block of lead brick may be handled to observe how heavy they are compared to a block of coal of about the same size. This is because a mercury atom or a lead atom is much heavier than an atom of carbon.

In nature many substances are known with atomic weight larger than that of lead. One such element is uranium. Towards the close of the last century it

*One million is equal to ten lakhs and one thousand million make a billion. 'Billion' occurring twice in the statement 'six hundred billion billion atoms' is not a misprint !

was found that uranium, left to itself, emits radiations which affect photographic papers, cause harmful burns to the human body, and can be detected by special counters. Because of the spontaneous emission of radiations such an element has been called radioactive. Very soon other radioactive elements—most famous being radium—and the radiations emitted by them were studied in detail. Using special machines which accelerate subatomic particles to high energies, many elements lighter than lead have been artificially converted to radioactive elements by bombardment with the energized particles. The radiations emitted by the radioactive elements comprise tiny subatomic particles of two types called alpha and beta and light of wavelength very much shorter than that of visible light called gamma-rays.

All these studies have revealed a clear picture of an atom, unexplored earlier by chemical methods. It has been found that each atom has a central nucleus bearing a positive charge with a cloud of tiny negatively charged particles called *electrons* surrounding it. The total positive charge in the nucleus is exactly equal to the total negative charge of the electronic cloud so that the atom as a whole is neutral. The atom is like a solar system in which the nucleus plays the role of the sun and the electrons that of the planets. The size of an atom is, therefore, determined by the extent of its electron cloud and its radius is a few Angstrom units, as stated earlier. The nucleus at the centre of the atom is, however, a very much smaller object and for measuring its dimension even the Angstrom unit is too large. In fact, if an Angstrom is divided into one lakh equal parts, each such part, called one Fermi unit, is suitable for expressing nuclear dimensions. A nucleus of a heavy atom like lead or uranium has a radius between six and seven Fermi units.

The structure of the nucleus of an atom has also been very thoroughly investigated during the present century, mostly after the thirties. Each nucleus is a tightly bound structure of many particles of two different kinds, called protons and neutrons. A proton carries a positive charge equal to the negative charge of an electron, and is nearly two thousand times heavier than an electron. The number of protons in the nucleus of an atom is equal to the number of electrons in its electronic cloud. The other fundamental particle, neutron, contained in the nucleus of an atom is electrically neutral and has a weight very slightly larger than that of a proton. Its presence in the nucleus, therefore, only adds to the weight of the atom. The identity of an element is determined by the number of protons in the nucleus of its atom. Nature, however, has some freedom with the number of neutrons in the nucleus of the atom of any element. For light stable elements encountered in nature the neutron number is very nearly equal to the proton number. For heavier and heavier elements the neutron number in the nucleus is much higher than the proton number. For example, the nucleus of a light element like oxygen has eight protons and

eight neutrons, whereas a heavy element like lead has 82 protons and 126 neutrons in its nucleus. Because of the freedom available to nature in choosing the number of neutrons, we also find in nature some oxygen atoms that have eight protons and nine or ten neutrons. These heavier atoms of oxygen are mixed in very small but definite proportions with the normal oxygen (eight neutrons) in a naturally occurring sample of oxygen gas. Atoms of an element having different weights are called different *isotopes* of the same element. Even the lightest element occurring in nature, hydrogen, contains another heavier isotope called deuteron (one neutron and one proton) mixed in very small proportion with the normal isotope (one proton). Hydrogen also has a third isotope called tritium, having one proton and two neutrons, which is radioactive. For obvious reasons deuteron is called heavy hydrogen. A normal molecule of water contains two atoms of hydrogen and one atom of oxygen. A water molecule in which hydrogen atoms have been replaced by deuteron atoms is called a molecule of heavy water. Normal water contains a very small but definite proportion of heavy water mixed in it.

It has been already stated that naturally occurring elements heavier than lead are radioactive as is indicated by the spontaneous emission of alpha, beta, and gamma rays from their nuclei. These nuclei are unstable and hence they ultimately convert themselves to stable nuclei by emitting subatomic particles. The radioactive decay of a nucleus has a lifetime which extends from fractions of a second to many thousand years depending on the element under consideration.

In addition to spontaneous radioactive decay, the nucleus of a heavy element like uranium is also unstable towards fission, that is splitting up into two nearly equal parts. Natural uranium is predominantly composed of an isotope having 92 protons and 146 neutrons. The total number of particles in the nucleus is thus 238. The isotope is, therefore, called uranium 238 and is denoted by professional scientists with the symbol U^{238}, where U stands for the first letter of uranium. Natural uranium also contains a very small part of another isotope, uranium 235, which has 92 protons and 143 neutrons. Both these isotopes of uranium undergo fission when struck by a neutron. A slow neutron initiates fission in uranium 235, whereas uranium 238 needs a much faster neutron to cause its splitting. Each of the two fragments of the fission process has, to start with, a proton and neutron number equal to *nearly* half the number of protons and neutrons respectively in uranium, that is, about 46 protons and 73 neutrons. For reasons of stability the two fragments formed by fission are, in fact, not *exactly* equal; the slightly larger one has a proton number close to 50 and the smaller one close to 40. With these proton numbers, the isotopes of stable elements occurring in nature have neutron numbers in the ranges of 60-70 and 50-60 respectively; that is, between two such nuclei a

total number of about 130 neutrons can be reasonably accommodated. The fissioning nucleus U^{238} or U^{235} has more than 140 neutrons. Thus the two fragments of fission of such a nucleus initially has a large neutron excess, and they emit some of these and also undergo radioactive decay to eventually convert themselves to stable nuclei with appropriate balance between the proton and neutron numbers. Some neutrons are also emitted directly by the fissioning nucleus when it is struck by the neutron eventually causing fission.

The spontaneous emission of neutrons during the fission process is a key factor in utilizing fission as a source of energy. Each fissioning nucleus emits a large amount of energy, several billion times more than the energy released in burning a carbon atom with a molecule of oxygen in the ordinary chemical process. However, to use fission as a viable source of energy, it is to be ensured that once it is initiated in a bulk quantity of the fuel (i.e. the fissile material), the process of involving further and further nuclei of the fuel in the release of energy should be automatic. This is to be compared with the obviously fulfilled fact in the case of burning coal after it is lighted with a match stick. In the case of the nuclear fuel the automatic spreading of the fission process in the fuel material after the initial fission of a few nuclei with neutrons (comparable with the lighting of coal by a match stick) is ensured because several neutrons are produced as a result of each fission. These neutrons then attack the neighbouring fissile material and the process propagates in a chain. The design of a nuclear reactor, the machine that produces nuclear energy on a controlled commercial scale, is made in such a way that these neutrons do not escape into the surroundings. The fissile fuel material rods are arranged at the core of such a device with each rod surrounded all around by a substance called 'moderator'. The neutrons produced from the core collide with the moderator atoms, get slowed down, and are thus confined inside the reactor to produce more fission in the atoms of the fuel rods. As a matter of fact, the total number of neutrons available at any instant is usually kept under control by pushing in or out rods of material that quickly absorb neutrons. Without this control mechanism the chain fission process develops so quickly in a bulk quantity of the fissile material that an explosion results. For each fissile material there is a critical mass above which a bulk quantity of the material displays uncontrolled fission reactions in a chain. This is what is deliberately permitted to occur in the detonation of a nuclear bomb (the so-called 'atom' bomb) in which two bulk quantities of the fissile material, each weighing below the critical mass, are allowed to merge together taking the total weight above the critical value.

Towards the close of the second World War two nuclear bombs were dropped on Hiroshima and Nagasaki in Japan. Several years before this a group of scientists in the U.S.A. under the leadership of Enrico Fermi designed

and successfully operated the first nuclear reactor under controlled conditions. Since then we have come a long way. From small research reactors scientific and technological advances have been made to the present-day giant nuclear reactors, each producing several hundred and even more than a thousand megawatts of electrical power. India made an early beginning in this field. Starting in 1956 with the first indigenously built research reactor 'Apsara', our latest achievement is the commissioning in July 1983 of the power reactor-1 at Kalpakkam built entirely by Indian scientists and engineers.

Another important nuclear process that releases enormous amount of energy is nuclear fusion. In this process very light nuclei, like hydrogen, deuteron, tritium, fuse with each other to produce heavier nuclei. In order that such fusion can take place and be sustained, an extremely high temperature as is prevalent in the sun and other stars is a prerequisite. It is, therefore, very often called the thermonuclear process. In the sun and the stars we have spectroscopic evidence of the presence of many heavy elements, all of which have been produced in successive stages by thermonuclear changes starting with the hydrogen gas. Under such high temperatures, electrons of the normal atom separate away from their nuclei, and the atom is then said to exist in an ionized state. A gaseous state of ions and electrons, as a whole electrically neutral, is called a plasma. Thermonuclear fusion research using plasma produced in the laboratory is being very extensively carried out in many laboratories of the world. The fusion that is being attempted in these researches is that of deuteron and tritium. When successful, this will bring within man's reach an almost unlimited source of energy using as source materials the heavy hydrogen extracted from sea-water and lithium found in earth's crust. In India a beginning has already been made in thermonuclear research. Success in this type of research and specially development to the point of commercial viability of fusion energy are still quite far off even on the global scene.

ENERGY THROUGH THE AGES

Let us now look into man's efforts at discovering and utilizing newer and newer sources of energy culminating in nuclear energy a few decades ago. In the process man has created more leisure for himself and as a social being has created richer and richer forms of culture.

The only source of energy available to primitive man was his own muscular energy derived from the assimilation of the food he ate. After man domesticated animals, his own muscular power for many purposes was substituted more efficiently by that of animals. It took many years before man learnt to produce fire. Fire served him initially to cook his food, later in kilns to produce bricks and earthenware and much later, when the use of metals became known, to

carry out elementary metallurgy leading to the production of tools and ornaments at various stages of his cultural development. As fuel for producing fire man depended for a long time on firewood, dried leaves, and organic waste of domestic animals which together comprise what is called biomass in today's terminology. Use of animal tallow, and later organic oils, for illumination is also of primitive origin. Tapping wind power for the navigation of sailing-boats dates back to fairly early days in human history. Surprisingly, the use of hydro-power is of comparatively recent origin and so is the use of fossil fuel and mineral oil.

The present-day civilization and its various cultural milieu are dependent very heavily on the use of coal, natural gas, petroleum, diesel, hydro-power, and fissile materials as the main sources of energy. The fuel is first burnt to produce heat which can be converted to locomotion with the help of various heat engines. These are directly used in individual and commercial transportation. Hydro-power produces locomotion in turbines which drive generators of electricity. Fissile material producing nuclear energy is used in the core of a nuclear reactor; the energy delivered by fission is removed as heat by a coolant, and the heat is used in steam turbines coupled to generators of electricity.

Because of the very convenient mode of transmission of electricity from its generation site to the premises of consumers, and its adaptability of being used for illumination, heating, as well as locomotion, electricity plays the most dominant role as the consumable form of energy in today's human society.

In the Mohenjo-daro and Harappā civilizations of pre-historic India evidences have been found of the use of domestic animals and organized human labour. Although fortifications of cities by embankments against flood water were known, there is no evidence that such embankments were ever used to exploit the mechanical power of river water. The Aryans, who came to this subcontinent as a nomadic tribe, destroyed the cities of Harappa civilization and eventually produced a pastoral culture by the cross fertilization of the native culture with what they brought as their own. Extensive use of fire in a deified form in their daily life and in their sacred religious rites is well known. Indra, perhaps the mightiest leader amongst the Aryans, has been described in the *Ṛg-Veda* as the king of gods and himself the god of rain having command of the thunder as a weapon. Varuṇa was worshipped by the Aryans as the god controlling air and water. Hymns addressed to the Sun-god are also well known and are still in daily use by many Indians. In sum, even though the Vedic society in practice used only fire, it produced a culture with a sombre and reverential cognizance of the gigantic sources of energy under Nature's control.

Absolute reliance on muscle power, on the physical power of domestic animals, on organic fat and oil, on fire produced with biomass, and on wind

power for navigation in the primitive human societies all over the world, including this subcontinent, continued perhaps for several millennia till the beginning of the Industrial Revolution in Europe. Mining of fossil fuel, invention and exploitation of steam power in locomotion, and eventually the production and use of electricity gave rise to a varied and extensive use of energy by human societies. Invariably, far-reaching cultural changes took place as a result of transformation of the pattern of day-to-day life, availability of more leisure, and that of more sophisticated goods and implements as material and cultural aids.

Due to the colonial and feudal exploitation and the consequent poverty and material degradation of the people of this subcontinent at that crucial juncture of human history, these far-reaching changes in the pattern of energy consumption elsewhere in the world remained restricted here within a very small segment of the society and that too under the technological and commercial control of the foreign rulers. Because of the alien control it failed to become an intimate and integral part of even the small layer of the society enjoying the fruits of the new sources of energy. In the vast rural expanses of the country where the majority of the people lived, and still live, in primitive agricultural societies, the pattern of energy usage remained essentially unchanged. Coal reached a fraction of the multitude of villages only to be used in the age-old family hearths, fire places, and kilns of traditional artisans. A painstakingly slow process of transformation of energy usage in the villages has started only over the last three decades; diesel agricultural implements, electrically driven or diesel-driven pump sets, electricity for household illumination and rudimentary comforts are now gradually trickling into the rural communities.

RATIONALE OF NUCLEAR POWER DEVELOPMENT

The production, control, and planning of energy on a national level passed largely into the hands of the Central and State Governments after independence. As a result, a rapid integration of the various modes of energy consumption in the daily lives of at least the urban societies in this country is already perceptible. By virtue of the sheer number of villages involved, even a modest rural electrification scheme and a programme of energizing agricultural pump sets, call for such a vast increase in the production of energy that the resource mobilization and target achievement in this respect have fallen below the demand in each successive five-year plan. By 1983 about 55·7 per cent of Indian villages came under electrification and about five million agricultural pump sets were energized. Nevertheless, rural energy consumption still constitutes only about 5·5 per cent of the total.

The energy need in the urban areas, specially that due to expanding industrialization and commercial activity, and due to modernization of the quality

of urban life, has also far outstripped the organized generation capability. As a result, small private diesel generator sets for augmenting the commercial supply in the urban areas have become a part and parcel of the daily life. The lion's share of energy consumption is still located in the urban industrialized pockets. The industrial sector alone accounts for 75 per cent of the direct use of coal, 50 per cent of electricity, and 26 per cent of oil consumption. The transport sector, which comes next, takes about 20 per cent of total available commercial energy.

In the earlier part of the three decades of energy development, hydro-electricity, generated at the sites of specially erected dams across selected rivers, played a major role. Gradually the emphasis in the planning has shifted to 'Super Thermal Stations' located as near the coal pitheads as possible. Very recently consideration is again being given to hydro-power development by establishing the National Hydro-electric Power Corporation (NHPC).

The coal resources of India are generally poor in quality with large ash content and only about 25 per cent is in good quality coking coal. The estimated reserve of coal is about 85 billion tonnes at depths up to 600 metres and in seams of more than 12-metre thickness. The annual mining in 1982-83 was about 132 million tonnes which roughly indicates that our coal reserves may not last more than a few hundred years at its present rate of depletion.

Further development of hydro-electricity by NHPC presents a formidable challenge because much of the large-scale potential now exists in the difficult terrains of the Himalayas. Small-scale hydro-projects, fashionably called 'mini' and 'micro', have a fairly optimistic prospect and are under active consideration by the respective State Governments.

India produces only half of her total requirement of oil and natural gas. It has an estimated reserve of about 15 billion tonnes of oil and oil equivalent gas, of which about 60 per cent is located off-shore. The estimated recoverable quantity is about 471 million tonnes of oil and 420 million cubic metres of gas. Although great strides have been made in inland and off-shore prospecting, drilling, and production, the natural resources here will always fall far short of our demand.

Besides hydro-electricity, other renewable energy sources are tidal waves, wind power, geothermal energy, and solar energy. Attention has been concentrated on these sources only in recent years all over the world in the wake of the oil price hike by the Middle East countries. Much of the progress on these energy sources is still in the research and developmental stage. In India the tidal power development potential has so far been estimated only for the coast of Gujarat. Wind mills, although popular in Europe for several centuries, have only recently caught the imagination of Indian small-scale technological development agencies. Some viable units have been produced on a small scale

and are being field-tested in limited areas. Elsewhere in the world developmental work is progressing on the utilization of wind power on sea-coasts with suitable air turbines. Geothermal energy, that is the heat energy contained in the interior of the earth, is easily accessible in certain areas of the world in the form of hot water springs and natural steam coming out of fissures in the earth's surface. The potential of such energy in India is yet to be prospected. Finally, the development of solar energy which is available in abundance in India, is still in its initial stage. Even globally speaking, a lot of development has yet to take place before it becomes commercially viable.

India's programme of nuclear power development has to be viewed in this overall context. We have at present an installed nuclear capacity of about 1,100 megawatts and, according to the present plan, this will go up to 10,000 megawatts by the turn of the present century. The last figure represents about 10 per cent of the projected total generation by the country in the year 2000 A. D., taking all the different energy sources into account. For the development of nuclear power, a target of 10 per cent of the total generating capacity is by and large the minimum adopted by most countries of the world, some of them having at present a level of development lower than that of India in nuclear know-how, trained manpower, and other resources. This point and some related questions which are of late debated upon in various forums will be considered in more detail in a later section.

NUCLEAR POWER PROGRAMME

India's early entry into the field of nuclear science and technology was the result of a far-reaching vision of two of her illustrious scientists, Homi J. Bhabha and Meghnad Saha. The older of the two, Saha, is recognized as one of the great astrophysicists that the world has produced so far. As a young lecturer in 1917 in the newly formed Physics Department of Calcutta University he had been educating himself in all the contemporary developments in the theory of relativity, quantum theory, and atomic spectroscopy, simultaneously strengthening through his preparations for classroom lectures the basic groundwork in classical subjects like electro-magnetic theory, heat, and thermodynamics. This versatile background sharpened his interest in the basic observations of stellar spectra accumulating at that time, and culminated in 1920 at the age of twenty-seven in his most outstanding contribution on the thermal ionization of atoms and its role in explaining the spectra of elements residing in stars. The recognition abroad, gained by this work, secured him an entry into the international world of physicists at that crucial era of far-reaching developments in the forefronts of physics. While he was a Professor at Allahabad University, a position he joined in 1923 after a trip to Europe, he started acquiring an interest in the developments of nuclear physics which is reflected in the records

of his lectures and writings around 1930 and thereafter. After the discovery of neutrons in 1932 by Chadwick, he realized immediately that these chargeless nuclear particles, when used as projectiles, would be very effective in penetrating different nuclei. He was himself trying to acquire a neutron source when he came to know of the important neutron experiments performed by the Italian physicist Enrico Fermi (who later migrated to the U.S.A. and produced the first nuclear reactor) and his collaborators in Rome University. When subsequently neutrons were used by Otto Hahn and his collaborators in Germany in 1938 (results published in January 1939) to produce fission of uranium nuclei, Saha soon came to know of this new discovery and became acutely conscious of the potentiality of this phenomenon as an energy source. He took up the Palit Professorship in Physics of Calcutta University in 1939 and in a few years introduced nuclear physics in the M. Sc. curriculum of the University. With the meagre resources of the Palit Laboratory he started developments in basic nuclear science and instrumentation. With a grant from Sir Dorabji Tata Trust he undertook to build a nuclear accelerator called cyclotron for energizing atomic particles. This machine took several years to take shape and ultimately worked successfully in 1958 in the Institute of Nuclear Physics founded by him in 1948 (officially inaugurated in 1950) under the auspices of Calcutta University to carry out researches in various aspects of nuclear science. After Saha's death in 1956, the Institute has been renamed Saha Institute of Nuclear Physics, and has since been funded as an autonomous institute by the Department of Atomic Energy (DAE), Government of India.

Homi Jehangir Bhabha was educated in Cambridge, England, in the thirties when he came into first-hand contact with the early developments in nuclear physics, elementary particle physics, and cosmic rays. His own contributions to the theory of elementary particles and cosmic rays earned him early recognition in the international physics community and brought him in touch with the foremost European physicists like Pauli, Fermi, and Kramers. He returned to India in the early forties and set up a research group in the Indian Institute of Science, Bangalore. He was aware at that time of the potentiality of nuclear fission as a source of energy. In 1945 he founded the Tata Institute of Fundamental Research in Bombay under the co-sponsorship of Sir Dorabji Tata Trust and the Government of Bombay (now Maharashtra) with a mission to develop this Institute of reasearch into a cradle for trained manpower for India's nuclear energy programme in particular and modern scientific and technological developments in general. This Institute has served its purpose very amply and is now the premier autonomous research institute in the country funded by DAE.

The years following 1940 are the important formative years for India's nuclear energy programme. Both Bhabha and Saha were conscious during

these years that India needed a very broadbased national policy, programme, and a statutory framework for development and exploitation of our nuclear resources under the auspices of the Government of India. Saha meticulously collected all the information on nuclear administration and development trickling from the major western countries through the veil of secrecy maintained by them during those early years. He was disseminating all this information periodically through a semi-popular science journal called *Science and Culture* of which he was the editor. He visited the U. K. and U.S.A. in 1944 as a member of the Indian Scientific Mission and tried to gather as much 'unclassified' (no longer secret) information as possible by utilizing his reputation and personal friendship with the leading scientists of those countries.

Towards the end of 1945 the President of the Council of Scientific and Industrial Research (CSIR) appointed an Atomic Energy Committee with Bhabha as its Chairman, and Saha, D. N. Wadia, and S. S. Bhatnagar as members. After 1947 Bhabha succeeded quickly in gaining the confidence of the independent country's first Prime Minister, Jawaharlal Nehru, who committed his Government to the task of developing a full-fledged nuclear energy programme in India. Nehru needed very little to be convinced that a power hungry country like India of 1947 would have to go all out for nuclear power as an alternative viable energy source so that all-round technological progress of the country could be achieved specially in areas like Rajasthan, far removed from the coal belts and sources of hydro-electricity.

The Atomic Energy Act was passed on 15 April 1948. Immediately afterwards, the Atomic Energy Commission (AEC) of India was established (August 1948) with Bhabha as its Chairman and with the explicit mandate to survey the entire country for radioactive minerals necessary for an atomic energy programme, to generate sufficient technical and scientific expertise in this field in terms of manpower and equipment, and to encourage and support research in its own laboratories and in other institutions in the country. The Ministry of Atomic Energy was set up under the Prime Minister and Bhabha was appointed Secretary to this Ministry. He thus possessed the unique privilege of combining in himself the powers of policy decision as the Chairman, AEC, and executive implementation as Secretary to the Ministry. He was also at the same time Director of the Tata Institute of Fundamental Research where a beginning had already been made for a base for advanced research and development.

In 1954 AEC decided to set up the Atomic Energy Establishment at Trombay which was formally inaugurated by the Prime Minister in January 1957. It was renamed Bhabha Atomic Research Centre (BARC) after the death of Bhabha in 1966. Since its inception this establishment has carried out development work in all relevant branches of our nuclear energy prog-

ramme starting from nuclear fuel technology to the designing, building, and operation of research reactors; recovery of plutonium (a fissile material) by processing the spent fuel from reactors; development of electronics necessary for nuclear technology; and a host of other works. Many of the developmental works carried out here have led to the formation of independent viable units which have been eventually transferred to other sites and now form an integral part of a vast complex under the administrative control of DAE.

The formative years of India's nuclear programme truly end with our account of the creation of the Atomic Energy Establishment. It would, however, be relevant to add a postscript on what would seem to be a set of paradoxes to any impartial chronicler of the contribution of the two masterminds, Bhabha and Saha. Except for the Institute of Nuclear Physics which now bears Saha's name, and the curriculum in many Indian universities on nuclear physics which Saha initiated, no other concrete monument to Saha exists today in India's achievements in the field of nuclear science and technology. His articles in *Science and Culture* are admirable documents and bear testimony to a very versatile mind, fully cognizant of the minutest details of the physics, chemistry, technology as well as the administrative structure of a nuclear science and energy programme. The timely dissemination of early information on these subjects through these articles must have played an important part in goading the Council of Scientific and Industrial Research to form the Atomic Energy Committee in 1945, and also in the quick formation of the Atomic Energy Commission after independence. Although a member of the former Committee, Saha was very paradoxically not included in the Atomic Energy Commission. The entire complex, built thereafter bit by bit under DAE, was Bhabha's own creation and testifies to his tremendous abilities as a scientist-architect. Saha became a member of the Indian Parliament in 1951 and till his death in 1956 tried to play a constructive role by offering many suggestions; his emphasis on the necessity of lifting the veil of secrecy from national as well as international nuclear programmes deserves mention in this context. Some of his recorded lectures in Parliament reveal that he was not fully aware at this stage of what was being done by the Indian AEC. To an impartial chronicler this again is a paradox, specially in view of the fact that the person concerned was an M.P., and he had many friends and students amongst India's leading scientists occupying high positions. His own writings reveal that he was gaining in those days a lot of information on the French Atomic Energy Programme from his friend Joliot-Curie, and yet apparently not enough of what was happening in India. The organizational structure, detailed plans, and programmes adopted independently by AEC were much in conformity with what Saha had advocated in his *Science and Culture* articles and still Saha had reasons

to be unhappy. His article written in collaboration with B. D. Nag Chaudhuri and published in 1945 in *Science and Culture* was totally off the mark while speculating on the detonation mechanism in an atom bomb and the article displayed complete unawareness of the authors about the concept of a critical mass of fissile materials. This is quite understandable because very little was known of nuclear fission to the outside world during those early days. Yet Saha had criticized in writing in 1954 an unrecorded statement by 'some men in power' who, according to him, 'have given out vaguely that we can do without uranium in atomic energy development' by utilizing thorium. This is once again a paradox because by 1954 the first phase of India's nuclear power programme comprising natural uranium reactors using heavy water as a moderator had been chalked out.

THREE PHASES OF INDIA'S NUCLEAR POWER PROGRAMME

It has already been said that natural uranium contains two isotopes, predominantly uranium 238 and a very small but definite proportion (1 part in every 140 parts) of uranium 235. Uranium 235 undergoes fission with slow neutrons and produces, on an average, more than two neutrons per fissioning nucleus. These neutrons are slowed down in a reactor by the moderator and produee fission of more uranium 235 nuclei. The process propagates in a chain and releases an enormous amount of energy which is removed from the core of the reactor by the circulating coolant material.

Reactors utilizing fission of uranium 235 with slow neutrons are called thermal reactors. If natural uranium is used as fuel in such reactors, the active material is the uranium 235 content of it. These reactors, for their successful operation, use heavy water as moderator and either heavy water or ordinary water as coolant. Indian reactors in the first phase of our power development programme, which is still continuing, are all of this type.

The majority of thermal reactors in the world, and specially the earliest ones, use enriched uranium as fuel. The enriched fuel is prepared by removing uranium 238 from natural uranium by a very elaborate and painstaking process, thereby making it richer and richer in its uranium 235 component. Since both the isotopes are chemically identical, no simple chemical process is applicable to such an enrichment procedure. The U.S.A. during the second World War, and closely following it other nations engaged in the nuclear programme, took several years to stockpile sufficient quantity of enriched uranium before launching upon their reactor projects. The intricate and expensive enrichment procedure of the fuel is, however, rewarded by the fact that natural water can serve as the moderator and coolant in thermal reactors with enriched uranium fuel India's first research reactor 'Apsara' built

indigenously and commissioned in 1956 is a reactor of this type with a very low power level. The enriched uranium fuel elements for this reactor were obtained from the U.K. Atomic Energy Authority. Our first two units of power reactor, each with a capacity of 210 megawatts, purchased on a turnkey basis from International General Electric of the U.S.A., and installed at Tarapur in 1969, are also of enriched uranium type.

Although uranium 238 present with uranium 235 in the fuel material does not undergo fission with thermal neutrons, it plays another important role. After absorbing a neutron uranium 238 becomes uranium 239, which is radioactive; it emits two beta-particles in succession and converts itself to plutonium 239 which is again a very useful fissile material and can be used as fuel in a reactor.

It is thus clear that when all the uranium 235 in the fuel elements of any first-phase reactor is completely used up in producing fission energy, the spent fuel rods are still very potent for all the plutonium 239 and unused uranium 238 they contain. An elaborate processing of the spent fuel is, therefore, done to recover the plutonium 239 and build up a stockpile. Unused uranium 238 is also recovered. The first plutonium processing plant of India was commissioned in 1964 at Trombay and with the experience gained a full-scale industrial processing plant at Tarapur was set up in 1979.

Sufficient stockpile of plutonium 239 is the primary requisite for launching the second phase of India's nuclear power programme. This fissile material will be used as fuel in the reactors of the second phase and thorium 232, extracted from the plentiful monazite sand of Kerala, will be used as a fertile material. The fertile material can be used in the thermal reactors of the first phase as well. It is called 'fertile' because it breeds a new fissile element, uranium 233 (another isotope of uranium which does not occur in natural uranium), when struck by the neutrons inside the reactor. In order that the chain process in the reactor be sustained, it is clear that on an average more than two neutrons should be produced per fission in this type of reactor. This is true for the fission of plutonium 239 caused by fast neutrons. One of the neutrons produced in the fission can produce further fission of plutonium 239, and the other is still available for attacking the fertile material and producing uranium 233. These reactors are called 'fast breeder reactors' and uranium 233 produced in them will be useful for starting the third phase of our nuclear power programme. The reactors in this phase will use uranium 233 as fuel together with thorium as the fertile material which will breed further quantities of uranium 233. The entire programme will thus be sustained and remain viable as long as our thorium supply from monazite sand lasts.

ACTIVITIES AND ACHIEVEMENTS

Except for further researches necessary for the third phase breeder reactors using uranium 233 fuel, India's preparations and capabilities for the programme depicted in the preceding section are complete. Starting in 1956 a series of research reactors have been installed and operated providing opportunities for research, for obtaining design data for new reactors and gaining valuable experience and confidence. A fully comprehensive complex of supporting facilities has been developed to sustain the entire nuclear programme and with backing from these facilities several power reactors for the first phase have been commissioned and work on a few more is progressing. A short account of all these activities and achievements is presented in this section.

Research Reactors: The first research reactor 'Apsara' was designed and built at Trombay in 1956. When this reactor became operational on 4 August 1956, it was the first reactor in Asia.

The second research reactor CIRUS was a gift from the Canadian Government under the Colombo Plan. The components of this reactor were all made in Canada but it was installed at Trombay by a joint team of Canadian and Indian engineers. It is a 40-megawatt natural uranium, heavy water moderated reactor with ordinary water as coolant. The uranium metal plant and fuel fabrication facility at Trombay were set up in 1959 for fuelling this reactor. Since then the uranium metal plant has diversified its activities.

A zero-energy research reactor ZERLINA was set up with indigenous expertise in 1961. It was decommissioned in 1983 after it had made many valuable contributions to new reactor design, concepts, and components.

India took her first step in fast reactor technology when a zero-energy fast reactor PURNIMA consisting of plutonium oxide fuel elements with molybdenum, copper, and steel reflectors was set up at BARC in 1972. The experiments carried out on this reactor are aimed at providing design data for a pulsed fast reactor (KPFR) to be set up at Kalpakkam.

India's first reactor using uranium 233 as the fuel became operational on 10 May 1984. It is named PURNIMA-2 and is in fact the only reactor in the world at present with uranium 233 fuel. The reactor core contains uranyl nitrate solution in water. Beryllium oxide is used as reflector of neutrons. Control and safety are ensured with cadmium absorber sandwiched between aluminium plates. As small a quantity as 900 gm. of uranium 233 made the reactor critical.

The latest research reactor DHRUVA is at present being built at Trombay. This 100-megawatt heavy water cooled and moderated reactor is fully designed in India and is being built with cent per cent Indian expertise. This reactor will be a very efficient and intense source of neutrons for research purposes.

All our thermal research reactors provide intense neutron sources for carrying on experiments in solid state physics, material science, radiation biology, and also to obtain various important data needed in designing new reactors. They are also used for the production of radioisotopes for nuclear, biological, and chemical researches and, what is most important, for clinical and therapeutic purposes. These radioisotopes have been extensively used at home and sold abroad. The tradition of this country in neutron research has been very well established due to the availability of our research reactors starting from 1956. Instrumentation for neutron spectroscopy at BARC has attained an excellence to the extent that recently one such sophisticated instrument has been installed at the Rutherford Laboratory in England.

Power Stations— (i) *Tarapur Atomic Power Station (TAPS)*: Some details on this power station are already given in the preceding section. It is by now public knowledge that the U.S.A. created problems in the delivery of enriched uranium fuel in violation of contract terms for the two Tarapur units, but the problem has now been solved. The first consignment of enriched uranium has been received from France in May 1983 and arrangements are in progress for procuring spare parts for these two units by indigenous manufacture and by purchase from alternative foreign sources.

(ii) *Rajasthan Atomic Power Station (RAPS)*: It consists of two natural uranium, heavy water moderated units, each of 220-megawatt capacity, designed by Canada and built partly with its expertise. The first unit went into commercial generation in December 1973 and the second in April 1981. The first unit (RAPS-1) has been shut down since March 1982 due to leakage of ordinary water which is used to cool the end shields of the reactor vessel. Efforts are continuing to repair the defect.

(iii) *Madras Atomic Power Project (MAPP)*: The first of the two units, each of 235-megawatt capacity and similar to the units in Rajasthan, started commercial production on 27 January 1984; it has since been very successfully operating. The second unit is likely to go into operation in early 1985. Completely indigenously built, these 235-megawatt units will serve as standards for Narora and Kakrapara.

(iv) *Narora Atomic Power Project (NAPP)*: Work is progressing and the two units are scheduled to be completed between 1987 and 1989. The location is in U.P.

(v) *Kakrapara Atomic Power Project (KAPP)*: Work on site-infrastructure is progressing. The two units are expected to be commissioned between 1991 and 1992. The site is in Gujarat.

Heavy Water: For the supply of heavy water for all these power reactors an elaborate complex of heavy water plants has been established. The delay in the successful operation of these plants and the consequent short supply

of heavy water have come in for some public criticism. All efforts have now been geared up in this direction to overcome the deficiency.

Our heavy water plants are located at Nangal, Baroda, Tuticorin, Kota, Thal-Vaishet, Manuguru, and Talcher. The plant at Nangal is the oldest and uses electrolytic method—the earliest process by which heavy water was first produced. The plants at Baroda and Tuticorin are now operating continuously and most of the earlier teething problems have been overcome. The plant at Kota will complete its commissioning trials by the end of 1984. Construction work on the new plants at Thal-Vaishet and Manuguru is proceeding according to schedule. Most of these heavy water plants are linked to fertilizer plants for their supply of ammonia gas. Some of them also suffer from power cut problems imposed by local power supply boards.

The heavy water plants are based on several different processes of heavy water production. The plant at Thal-Vaishet, for example, is based on monothermal ammonia-hydrogen exchange process and the one at Manuguru utilizes hydrogen sulphide-water exchange process. At present attempts are on to make the ammonia based plants independent of fertilizer plants. A pilot plant set up at Baroda will soon try a new process in this respect.

Nuclear Fuel: India is completely self-reliant in all aspects of fuel technology—mining, processing, and fabrication in finished forms for use in the reactors.

Atomic Minerals Division with its headquarters at Hyderabad makes integrated surveys and exploration of uranium and other nuclear raw materials resources. Total indicated and inferred reserves of uranium oxide to the extent of 73,000 tonnes have been established through its efforts in different parts of the country.

Uranium Corporation of India Limited, located at Jaduguda and registered in 1967, undertakes mining and milling of uranium ores. Under the Corporation a new plant was commissioned in 1983 to recover uranium from copper tailings, and another uranium recovery plant is projected to be set up at Mosabani. The new Bhatin uranium mines project is expected to be completed in a couple of years.

The Nuclear Fuel complex at Hyderabad manufactures uranium fuel and zircaloy structural materials for nuclear power reactors.

Uranium metal plant at Trombay produced its first ingot in 1959 and has now been fabricating fuel assemblies for the research reactors in BARC. Design and fabrication work for a new fuel containing plutonium carbide and uranium carbide for breeder reactors and also development work for uranium 233 based fuel have been undertaken at BARC.

Indian Rare Earths Limited registered in 1950 operates a plant at Alwaye in Kerala to process monazite from beach sand and a plant for producing

thorium from monazite at Trombay. It is now setting up another sand complex at Chhatrapur in Orissa.

Breeder Reactor Programme: A Reactor Research Centre (RRC) has been established at Kalpakkam in Tamil Nadu with the purpose of developing fast breeder reactors. These reactors have to be cooled more efficiently than thermal reactors, and therefore liquid sodium is to be used as coolant in them. The entire liquid sodium cooling system has been indigenously developed and tested. A new plutonium rich fuel containing plutonium carbide and uranium carbide has been developed at BARC. Stainless steel clad fuel pins are being fabricated. The immediate aim is to install a 40-megawatt thermal power fast breeder test reactor (FBTR) for which almost the entire assembly is complete. It will deliver 16 megawatts of electrical power and is expected to be installed by the end of 1984.

The FBTR project, manned entirely by Indian engineers and physicists, is based on design diagrams from France for its fast breeder reactor named *Rhapsodie*. Components for the project are all fabricated in India. The next project scheduled for Kalpakkam aims at building a 500-megawatt prototype fast breeder reactor (PFBR).

DISCUSSION ON THE CONTROVERSIES

In view of India's present target of installing a nuclear capacity of 10,000 megawatts by the turn of the century, some criticism has been voiced in various public forums on two accounts. First, whether Indian capability and past records justify undertaking such an ambitious programme and, second, whether the intrinsic environmental hazards posed by nuclear radiations ought to deter us from further expanding the scope of nuclear power generation. As a matter of fact, very staunch environmentalists and pacifists in the western countries, and some in India, strongly advocate closing down of all nuclear installations everywhere in the world. The two questions posed here will be examined in this section.

It is now well known that on 18 May 1974 a nuclear explosion experiment was carried out underground by DAE at Pokhran in the Rajasthan desert. It was a plutonium device placed at a depth of 107 metres and designed to yield about 12 kilotons of explosive energy, i.e. equal to the energy released in the explosion of 12,000 tons of TNT (a chemical explosive). The explosion was completely contained underground and there was no release of radioactivity into the atmosphere. Various measurements have been made during and after the explosion to collect scientific data.

The impact of this experiment on the international scene had been tremendous. The Canadians immediately withdrew all their collaboration in the Indian atomic energy programme including their participation in setting up the Rajasthan power project. No help from France, Germany, and

Switzerland, which had provided us the know-how for a couple of processes for producing heavy water, was any longer available in overcoming the difficulties encountered by us in the heavy water plants. The United States, contrary to the terms of the original contract, imposed an embargo on all spare parts and enriched uranium fuel for the Tarapur Atomic Power Station.

It cannot be denied that the slippages in our atomic energy programme for a few years after 1974 occurred due to the sudden withdrawal of the international collaboration. The advanced countries put pressure on India to sign the nuclear non-proliferation treaty and accept an overall inspection of all our nuclear installations. India has refused to sign such a treaty, and has offered to have an international inspection of the stockpile of fissile material resulting only from installations built for us by other countries. On the international scene this attitude is very often interpreted as Indian intransigence. However, it would be pertinent to point out here that India's present attitude is not tied to her success at Pokhran; it is the continuation of a consistent policy adopted many years ago. Even as early as 1954 during a debate in the Indian Parliament, Nehru had outlined our policy that India should never agree to an international inspection of her own atomic energy installations. According to him, nuclear power would be essential for the development of a country like India; but it was not so essential for countries with adequate power resources which could, therefore, afford to accept controls. Nehru asserted that an international agency with the power for unlimited inspection and control would virtually become a super state body and no independent country should jeopardize her freedom by agreeing to such inspection.

After the initial slippages, mentioned above, India has now overcome most of the problems. It has already been described that we have now designed, erected, operated, and standardized a 235-megawatt natural uranium power reactor like the one Canadians were helping us to build at Rajasthan. We are self-sufficient in all aspects of fuel technology, plutonium separation, and radioactive waste disposal. However, the situation for the production of heavy water, as will be evident from the preceding section, is still not completely satisfactory. All the problems encountered in the heavy water plants are being faced, and are to be faced, entirely by our own investigations and experience. Fortunately, considerable progress has now been made in this direction. With the successful operation of all our plants we shall have adequate heavy water to support a power programme of about 5,000 megawatts. Two or three larger heavy water plants or purchase of heavy water from abroad (if available) will be needed to meet the requirements for the projected 10,000-megawatt generating capacity.

With the currently standardized 235-megawatt units, and a 500-megawatt unit to be designed, operated, and standardized by the early nineties, the

target set for the year 2000 appears reasonably within the country's technological reach. The economics of electricity generated from nuclear fuel *vis-a-vis* coal has also been studied in good detail. Taking about nine years to be the construction period of each nuclear power station, it has been established that in the nineties the cost of nuclear power stations will be quite competitive with, if not cheaper than, the coal-based thermal stations located at pitheads. It has also been estimated that the revenue earned from the sale of electricity will overtake the investment on the proposed nuclear power stations before the end of the century.

The Organization of Economic Co-operation and Development (OECD) comprising all the West European countries, Turkey; the U.S.A., Canada, Japan, Australia, and New Zealand set up a Nuclear Energy Agency (NEA) in 1972 which publishes periodically all up-to-date data and future projections up to the year 2025 on development of nuclear energy by their member countries, the East European bloc countries, and the developing Third World countries. Some of these data in relation to the first point of controversy, mentioned at the beginning of this section, are interesting. Brazil, having 250 megawatts of nuclear capacity in 1980, expects to install a total of 630 megawatts in 1985 and 5,610 megawatts in 1990. The corresponding figures for the Republic of Korea are 560, 3,590, and 9,890 megawatts respectively. For even a small country like Taiwan the figures are 1,210, 4,020, and 6,700 megawatts. The total capacity of all the OECD countries, taken together, is expected to rise from the present figure of 120,000 megawatts to 350,000 megawatts in 1990 and about 680,000 megawatts in the year 2000. The same figures for the U. S. S. R. and her associated countries are 17,000, 75,000, and about 290,000 megawatts respectively. Leaving aside OECD and the Soviet bloc countries, rest of the world (India is included here) produces at present 3,000 megawatts and this figure will rise to 30,000 and 120,000 megawatts in the years 1990 and 2000 respectively. At the end of 1982 the installed capacities of the U. S. A., France, Japan, and the U. S. S. R. were 60,000; 20,000; 16,000; and 17,000 megawatts respectively. France envisages that by the end of the century, her total nuclear capacity would represent about 70 per cent of her total power generation.

All these data would strengthen the argument of a country having significant nuclear capability to undertake an ambitious expansion programme for the future. The following excerpt from an OECD report will further stress another significant argument: 'While it has taken 20 to 30 years to train and assemble the highly skilled resources for nuclear energy design, engineering and manufacturing, this talent could well dissipate rapidly in the absence of expectations for future survival and growth.' This must be a very vital consideration for a country like India after having invested substantially on

establishing the strong indigenous base of manpower and the resources for nuclear technology.

By now the first point raised at the beginning of the section has been adequately discussed. Turning now to the second point, we must first note that, according to repeated statements by the Government of India (before and after the Pokhran blast), our nuclear policy has all along been, and still is, exclusively devoted to its peaceful utilization. The protests of pacificists against a nuclear armament to the teeth, which can wipe out the entire human civilization if a total nuclear war breaks out, need to be strengthened, but India's present nuclear programme cannot be accused on this count. The concern of environmentalists, however, applies to all nuclear installations, peaceful or warlike, and hence needs a closer examination.

It is true that the hazards of a nuclear installation, in the cases of accident, are quite enormous and accidents, though rare, have happened. However, it should be borne in mind that the safety regulations and standards of all nuclear installations are guided by stringent specifications of the International Commission on Radiological Protection (ICRP). In our own country the Radiological Protection Division of BARC is responsible for the maintenance and imposition of safety standards and procedures. This arrangement has recently been strengthened by establishing the Atomic Energy Regulatory Board outside the jurisdiction of DAE and reporting directly to the Atomic Energy Commission. All nuclear installations have several alternative lines of automatic safety devices to guard against unforeseen circumstances. The radioactive wastes are always stored and disposed of under regulated conditions. The basic principle is to concentrate and contain the radioactivity as much as possible and discharge to the environment only those streams that have radioactivity below internationally accepted levels. The solid long-lived wastes are ultimately vitrified and buried deep underground in suitable rocks. For low and intermediate level wastes, near-surface engineered storage is practised.

At present the quantity of waste released by our nuclear installations is so small by the standards of the advanced western countries that, truly and rationally speaking, waste disposal is still of very minor concern for India.

CONCLUSION

We thus come to the conclusion that India's present nuclear policy and the nuclear programme are quite sound and reasonable. The efforts of DAE in this field are also intimately linked with developments in other public sector and private industrial enterprises in the country because the latter are required to fabricate on contract a large number of components—mechanical, electrical, and electronic—for each power project. All these jobs, including materials preparation, involve extremely high quality and high precision work, a feature

with which our industrial enterprises executing such contracts are gradually becoming familiar, and indeed they have been facing this challenge quite admirably. There is a potential demand on an international scale in the developing countries for the small 235-megawatt nuclear power units we have been producing. These countries have meagre power grids for which super nuclear units of more than a thousand megawatts, which the western industrialized countries and Japan have been producing at present for their own use and export, are unsuitable. In our own country also the power grids need considerable improvement, a work that has already been planned and has made some progress. Because of the support from the industries we need, India is still not geared to accept a large number of international contracts. However, a great potentiality lies in this direction and all efforts need to be concentrated in developing the necessary infrastructure on a much larger scale than what exists now. Our own programme of ten thousand megawatts is indeed ambitious, but there is nothing basically wrong in harbouring such ambitions when we have the necessary resources and trained manpower. Much of our success will depend on the speed with which we can establish a power project in the future following standard designs. So far, this lead time has been close to twelve years although the initial estimate was about nine years. It would be essential to try hard and reduce the lead time to the estimated number of years. It may, however, be mentioned that according to OECD reports some of their member countries have also suffered in the recent past on this account; in the case of the U. S. A., for example, the lead time for various reasons has exceeded ten years. On the projected goal of total capacity also, OECD countries have a record of continuously being behind the schedule. In our own country the lead time of thermal power stations also, in most cases, lengthens considerably beyond project estimates. On the whole, the conservative view of the scenario appears to be that by the year 2000, the envisaged power installation programme in terms of thermal, hydro, and other alternative sources is likely to have a shortfall and in view of this, the programme undertaken for nuclear power generation has to be welcome. If there is a shortfall here, in spite of concerted efforts, the results achieved will still be very valuable in giving us confidence in indigenous know-how, expertise, and sophisticated collaboration and co-operation with other heavy industries in the country at large.*

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Source Books: (1) *Collected Works of Meghnad Saha*, Vol. 1, Orient Longman. ed. S. Chatterjee, published by Saha Institute of Nuclear Physics under the sponsorship of DST; (2) *Nuclear India* published by DAE; (3) *BARC Newsletter* published by Library and Information Services, BARC; (4) *Annual Reports*, DAE; (5) *OECD Reports*.

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SPACE RESEARCH

SPACE research in India, including space science and technology, has a long tradition. The first Indian satellite has been christened 'Aryabhata' after the famous mathematician-cum-astronomer, forging the link between modern India and her glorious past when astronomy and mathematics were used to determine the orientation and configuration of the stars, and to construct platforms for lighting the fires for the well-being of the community. Since then the instruments and tools for space research have changed keeping however in mind meaningful use of such space activities. In other words, space research in India has developed through space technology and engineering not only for the advancement of knowledge but also for the application of such knowledge to the service of humanity. While India cannot afford to send a man on the moon, the objective of space research will continue to be the best utilization of the fruits of space research for the quickest progress and development of the nation in the priority-oriented economic and social sectors so that it can contribute not only to its own welfare and growth but also to the peace and advancement of the international community. In fact, this very attitude of India in aiming at self-sufficiency in technology with a view to playing its proper role in the world has been of great help in the development of space research.

An important chapter in India's space research was opened between 1780 and 1790 when the Nungambakkam observatory in Madras initiated a new phase of study in the field of climatology associated with meteorology, weather prediction, and allied subjects. This area of applied science has today developed into one of the most advanced technologies, which utilizes satellites. The Madras astronomical observatory undertook studies in the fields of astronomy, geography, and navigation in India by systematic meteorological observations beginning around 1796. In 1823 the Colaba observatory in Bombay was established for astronomical and magnetic studies. In 1835 the Survey of India in Calcutta began to contribute to the knowledge of geophysical phenomena. The starting of the Trivandrum observatory in 1836 expanded the scope for astronomical and meteorological studies. Geomagnetic studies commenced in Simla in 1841. An additional observatory was established in 1852 on the summit of Agasthyamalai near Trivandrum at an altitude of 6,200 ft. above sea level. This observatory facilitated the study of the effect of altitude on magnetic and meteorological elements. The data thus obtained were necessary to verify

theories of semidiurnal oscillation of the tropical atmosphere. The discovery in 1858 of the 27-day periodicity in the daily variation of the geomagnetic field is one of the important contributions including 'the study of lunar and lunisolar variations of temperature and of time variation of the magnetic field during magnetic storms' by Moos at Bombay during this year that is also worth mentioning. The Agra observatory in 1862 and the Nagpur observatory in 1869 further widened the scope of studies of meteorological-cum-climatological subjects in this country. In 1875 the India Meteorological Department (IMD) assumed the responsibility of co-ordinating the meteorological studies reported from various centres. The establishment of a solar physical observatory at Kodaikanal in 1899 promoted the study of astrophysics. In the course of research at this centre it was found that fluxes of gases flew out from the regions above sun-spots. This discovery encouraged the space scientists in India, especially those dealing with astrophysics, solar-terrestrial physics including ionosphere, solar radio astronomy, solar X-rays, solar cosmic rays, and geomagnetism involving also studies on the interaction of solar radiation on the upper atmosphere.

STUDY OF UPPER ATMOSPHERE

In 1902 the Survey of India undertook systematic field observations for the preparation of terrestrial magnetic charts of India. Scientific studies on the mutual interaction of radio waves and the upper atmosphere began in 1925 when the University of Calcutta founded a wireless laboratory. Atmospheric studies and observations up to 35 km. dealing particularly with the distribution of temperature and humidity made rapid strides due to the efforts of IMD. It introduced many of the latest methods for weather studies using balloons and similar instruments. For example, by 1928 a pilot balloon section was established as an adjunct to the meteorological branch of the Trivandrum observatory. The balloon observations were supplemented with eye observations concerning atmospheric parameters like pressure and temperature from the weather station set up at Alleppey. This balloon section was helpful for not only routine duties and special services like navigation but also critical studies including radio research. Balloons carrying recording instruments called 'balloon sonde' were released from the Trivandrum station during the pre-monsoon period of 1938. The temperature, pressure, and humidity data collected at different heights were used by IMD and for the purpose of navigation etc. till these activities were suspended with the outbreak of World War II in 1939.

CRADLE OF SPACE RESEARCH

In 1932-33 India participated in the radio research programme of the Second International Polar Year. Ionospheric studies were started in 1933

at Bangalore and in 1934 at Allahabad where the study of astrophysics was an important field of work. Experiments on cosmic rays associated with high value of terrestrial magnetism, especially at high altitudes very close to the geomagnetic equator, were gaining momentum, leading to the establishment of an experimental unit in Bangalore in 1940 as a part of the Indian Institute of Science. This study of cosmic rays formed the nucleus of the work around which the Tata Institute of Fundamental Research (TIFR) was started in Bombay. The forties witnessed further advance in space research activities in that a radio research committee was created in 1942 for the purpose of upper atmosphere studies. Research in the field of cosmic rays also expanded at various centres in the country, especially at Bose Institute, Calcutta, and Muslim University, Aligarh. During this decade the Physical Research Laboratory (PRL) was established at Ahmedabad, which specialized in the field of cosmic rays and aeronomy and took a leading role in forming 'the cradle of space research in India'.

COSMIC RAY, AERONOMY, AND RADIO RESEARCH

Remarkable progress in the field of cosmic rays research was made during the fifties, principally at the centres located at Waltair, Varanasi, Ahmedabad, and Calcutta. Because of the tireless researches of the workers at these centres, India enjoyed a very admirable position in the field of upper atmosphere research in the world. The radio research committee of the Council of Scientific and Industrial Research (CSIR) began publishing in 1955 a co-ordinated monthly bulletin—*Ionospheric Data*—giving statistics of six Indian stations. Early in 1956 the Radio Propagation Unit was formed at the National Physical Laboratory (NPL) with the scientific staff of the radio research committee secretariat. This group undertook experimental work for studies of atmospheric as well as cosmic radio noise. The efforts of this group made it possible to utilize these natural radio emissions, especially by expanding the scope of studying radio wave propagation at very low frequency (VLF) and at very high frequency (VHF). The research of this group also covered the activities of the scintillation of radio stars at 60 megahertz (Mhz) by installing a C-4 automatic ionospheric recorder. The climatological-cum-meteorological studies, including cosmic ray, terrestrial magnetism, and radio research, flourished to such an extent that India proved to be an indispensable participant in the International Geophysical Year in 1957-58. In collaboration with the Smithsonian astronomical observatory, the observatory at Naini Tal undertook in 1957 the tracking of satellites. In 1958 TIFR flew successfully the first constant altitude plastic balloon made in this country. Encouraged by this initial success, arrangements for launching balloons were made at Hyderabad, from where many more major flights have been carried out since 1959. For efficient and reliable flights

special quality polyethylene films were used to fabricate these balloons, ranging in volume from very small to very large with a capacity of around 100,000 cubic metres. The large balloons could carry instruments weighing up to 250 kg. and maintain an altitude of about 36 km. for approximately eight hours. Cosmic ray research at low latitude in general and the geomagnetic equator in particular was facilitated by means of balloons, permitting the detection of very high energy cosmic ray particles that are admitted into the earth's atmosphere. With the addition of suitable equipment, the Hyderabad balloon launching facility was utilized for equatorial experiments by research workers not only from India but also from the U.S.A. and U. K. Because of the significant contribution of Indian scientists in respect of the knowledge of cosmic rays, especially from the geophysics point of view, India participated in 1959 in the world-wide space research activities of the International Geophysical Congress Council.

The beginning of 1960 was marked by several features in the further expansion of the field of Indian space research. The Physics Department of the University of Delhi initiated research this year on the ionosphere which yielded useful information on the ionospheric parameters as well as internal gravity waves. The first high altitude cosmic ray experiment with the Indian balloon launched from Hyderabad was successful and was able to collect very useful data for further advancement of cosmic ray research in the world.

PEACEFUL USE OF OUTER SPACE

In the latter half of 1961 the Government of India participated in the efforts of the international community for the exploration of outer space for peaceful purposes. This year also saw the establishment of the Real Time Satellite Telemetry station at PRL, Ahmedabad, in which the National Aeronautics and Space Administration (NASA) of the United States collaborated. This station made possible the gathering of data for the solar X-ray flux from the different NRL satellites as well as radio beacon data from S-66 satellites.

The Department of Atomic Energy (DAE) took a leading role in 1962 in the formation of the Indian National Committee for Space Research (INCOSPAR) with its headquarters at PRL, Ahmedabad. This was a landmark in India's promotion of space research for peaceful purposes and in her efforts for international co-operation in this field. The aims and objects of INCOSPAR were as follows:

> 'To advise the Government of India on the promotion of research in the exploration of space and its utilization for peaceful purposes; to promote international co-operation in space research and in the exploration and peaceful uses of outer space by actively participating in the work of the UN Committee on the peaceful uses of outer space and other inter-

national organizations with similar objectives; to liaise with the Committee on Space Research (COSPAR) of the International Council of Scientific Unions and other national and international research organizations by participation in the various scientific programmes and also to support national and international activities likely to promote the development of peaceful uses of space.'

THUMBA EQUATORIAL ROCKET LAUNCHING STATION (TERLS)

By this time rockets were already being used by advanced nations as a routine exercise for sounding the upper atmosphere. These sounding rockets, INCOSPAR thought, could also be launched in this country from the geomagnetic equator, especially where the upper atmospheric layers at the altitude between 90 and 130 km. revealed unexpectedly enormous diurnal variation of the terrestrial magnetic parameters. This phenomenon had also been observed by many other international scientists working in the field of geomagnetism and could be interpreted in the background of the existence of a concentrated zonal flow of electric current occurring in these layers of the upper atmosphere. This current flow formed a narrow current sheet of a width of about 600 km., termed 'equatorial electrojet'. It could serve as the object of many significant studies in the field of aeronomy, especially in the interaction of neutral and charged particles under the influence of terrestrial magnetic fields, coupled with the fact that the magnetic dip of the earth at the geomagnetic equator is zero, i.e. the lines of magnetic forces running from the south to the north pole are exactly parallel to the earth in this region. The only way to study the equatorial electrojet phenomenon was to conduct experiments with instruments that could be carried to an altitude of up to 200 km. on small sounding rockets. INCOSPAR allotted priority to such study, especially in the field of aeronomy, around this region of the upper atmosphere just beyond which satellites are used (which are rather costly for launching in the context of India's economy). This emphasis on launching sounding rockets from the geomagnetic equator had further support from the viewpoint of climatology, as it would help collection of valuable meteorological data. Thus a multipurpose goal could be achieved at no extra expense to the country. Based on these considerations, INCOSPAR started work towards the establishement of an equatorial sounding rocket launching facility at Thumba, Trivandrum.

As a preliminary step it was felt necessary to train up personnel in all aspects and disciplines required to support such a station through collaboration with NASA. Accordingly, an agreement was signed between DAE on behalf of the Government of India and NASA from the side of the Government of the United States. This agreement provided that Indian scientists and engineers would receive training in the areas of sounding rocket launching, including

ground support, at the launching station at Wallops Island and the Goddard Space Flight Centre, U.S.A. Simultaneously, work was undertaken for locating the area in Thumba and confirming its suitability so far as the geomagnetic equator was concerned with acceptable limits of the magnetic latitude etc. Since this station would serve virtually as the only international equatorial sounding rocket facility of its kind to support the United Nations' efforts for the peaceful use of outer space, experts from several leading space powers were deputed by the United Nations to help INCOSPAR in identifying the region in Trivandrum with appropriate instruments for detecting the zero magnetic dip locations. Thus a new era began in India's space research from both national and international considerations.

LAUNCHING OF SOUNDING ROCKETS

In 1963 the first International Seminar on Space Physics was organized in India by PRL at Ahmedabad. PRL was also given the administrative responsibility for TERLS (Space Projects) by DAE. In the later half of 1963 the first sounding rocket programme was inaugurated at TERLS. The rockets required for the initial series of experiments for this programme were not available in the country. Neither did India have the requisite radar for tracking the rocket trajectory or telemetry for communication between the rocket-borne instrumentation and ground-based receiver, for which a DOVAP ground unit was also required. All these requirements were met by the assistance of NASA. Further help with regard to the availability of rockets and radar came from the *Centre Nationale Études Spatiale* (*CNES*), France. Finally, the immediate need for a computer, a helicopter for surveillance, and a shake table for testing airborne instruments to determine the probability of their survival during launching in the rocket were provided by Hydro Meteorological Services of the U.S.S.R. Instruments for studying the upper atmospheric wind flow pattern by means of sodium vapour payload were launched on a two-stage sounding rocket made in France, called *Centaure*, on 21 November 1963 from TERLS. This joint experiment by Indian and French scientists was designed to study the dynamics and composition of upper atmosphere at equatorial altitude. The overall collaboration in this field of research in aeronomy was accomplished under the joint assistance of INCOSPAR, NASA, and *CNES*.

Meanwhile, further work was being carried out by Indian scientists on the practical application of space research to meteorology and climatology. It is well known that three quarters of the earth is occupied by ocean and there are many land areas that are not inhabited and meteorological parameters for all such regions are not available, because no climatological studies can be conducted in these places. In order to solve these problems, advanced nations started launching meteorological satellites that would orbit round the earth.

Series of spin-stabilized Tiros satellites, for example, can be utilized as observation platforms in space from which scanning of vast areas of the terrestrial atmosphere is possible in order to collect all sorts of atmospheric data that are transmitted to ground-based receiving stations by built-in automatic picture transmission systems (APTS) in these satellites. These systems have the capability for receiving and transmitting cloud pictures every 208 seconds with high resolution infra-red radiometer cameras in such a fashion that a large area covering about a million square kilometres of the earth's surface can be reached by meteorological stations in different parts of the world. Accordingly, IMD established an APTS at the Colaba Meteorological Centre where, in 1964, the first cloud picture was received from TIROS-VIII in collaboration with the World Health Organization and the National Science Foundation, U.S.A.

ROCKET RESEARCH AND DEVELOPMENT

In 1964 a team of scientists from UN visited TERLS in order to enlarge the scope of space research activities in India for collaboration with the world body. At about the same time, for promoting indigenous rocket manufacture and thereby ensuring the continuation of sounding rocket programmes, an agreement of collaboration was reached with *CNES/Sud Aviation*, France, for transfer of know-how to fabricate *Centaure* sounding rockets in India. Fabrication of these rockets with French know-how was entrusted to the Central Workshop of the Atomic Research Establishment (now called BARC) at Bombay. Apprehending that the licence from *Sud Aviation* was time-bound and that foreign know-how would also involve the import of materials, it was deemed essential to develop rockets of Indian design. With this idea in view, the Atomic Energy Commission approved the establishment of the Space Science and Technology Centre (SSTC) at Veli Hill, Trivandrum. This Centre was entrusted with the major responsibility of developing sounding rockets of superior performance as well as generating technical skill and expertise in aerospace engineering and scientific payload construction for rockets and satellites. To supplement the achievements of space research with rocket-borne instruments ground-based experiments were necessary for which this Centre was also given responsibility. In the meantime, electrojet study over Thumba came to prominence when a magnetometer was launched on a sounding rocket in 1964.

Impressed by the success in rocket-launching operations as well as by the data already generated by rocket-borne experiments, IMD became interested in initiating a programme of rocket meteorology. Accordingly, collaborative agreements were concluded between IMD and NASA. The initial experiments also encouraged the scientists of the U.S.S.R. to collaborate with India for upper atmospheric research from TERLS, and agreements were signed

between INCOSPAR and the Hydro Meteorological Services of the U.S.S.R. for closer mutual co-operation. By the end of 1964 sixteen sounding rockets were launched from TERLS with scientific instrumentation designed for experiments up to an altitude of 180 km. under the joint collaboration of India, France, the U.S.A., and the U.S.S.R.

EXPERIMENTAL SATELLITE COMMUNICATION

The year 1965 saw an interesting achievement in Indian space research and associated activities with the holding of the Second International Seminar on Space Science and Technology at Kodaikanal and TERLS under the joint auspices of UNESCO and INCOSPAR. Impressed by the series of successful launching experiments planned by the Indian scientists with international space research experts, the UN General Assembly accorded approval for UN sponsorship of TERLS. A preparatory meeting of the International Advisory Panel for TERLS was held this year.

That one of the most practical applications of space research is the utilization of satellites for telecommunication purposes came to be realized very soon. For example, when a satellite is orbiting the earth in a circular equatorial path at a height of 35,000 km. with the same velocity as that of the earth, it is 'geosynchronous', that is, stationary in relation to the earth. Thus a large part of the global hemisphere can be made visible to it because of its hovering at so high an altitude. Consequently, such an orbital position of a satellite facilitates visibility between two widely separated points along the earth's curved surface. This visibility, in turn, can establish a high-quality, reliable telecommunication link between these two points. Further, the usefulness of such a communication satellite for the transmission of television pictures over a wide network of T.V. receiving stations is enormous, because it can be an effective medium of mass communication to regions of isolated habitation, providing information about advanced methods of agriculture, family planning, adult education, etc. With a view to acquiring the capability and expertise in such communication INCOSPAR established at Ahmedabad an Experimental Satellite Communication Earth Station (ESCES) with aid from a special fund of the United Nations which approved the project in 1965.

Meanwhile, work in other fields of space research was advancing fast. Under the programme of the International Quiet Sun Year (IQSY) India took a leading role. NPL organized a symposium, and a balloon launching programme was conducted at Hyderabad.

PROGRESS DURING 1965-75

The growth of space research activities during 1965-75 was enormous. At the end of 1965 TERLS had already made seventeen sounding rocket

launchings. During 1966 eleven more sounding rockets were launched. At ESCES, Ahmedabad, the first International Training Course for Satellite Communication Technology was organized and T. V. link tests with Japan and Australia were successfully conducted. In the same year the first Indian rocket developed at SSTC and named *Rohini-75* was successfully launched from Thumba. Eight more sounding rockets were also launched from Thumba with success in 1966. An eventful era in the history of space research in India began in February 1968 when the Prime Minister dedicated TERLS as a UN-sponsored International Range. During this year India participated in the Third International Seminar on Equatorial Astronomy and Space Physics, and DAE was entrusted with the task of establishing a satellite communication ground station at Arvi near Pune. The Radio Service Division of NPL participated in several programmes of the International Years of Active Sun (IYAS) extending over the period 1969-71 and supervised by the Inter-Union Committee on Solar Terrestrial Physics (IUCSTP). These programmes relate to monitoring of solar-terrestrial phenomena; proton flares; ion chemistry of D and E regions; and sudden ionospheric disturbances.

In 1969 INCOSPAR was reconstituted under the national body affiliated to COSPAR, viz. Indian National Science Academy (INSA), and it continued to establish links with COSPAR. Though this Committee is responsible for promoting and supporting international co-operation in space research and in the peaceful uses of outer space, the programme of space research and its utilization for peaceful purposes was entrusted to the Indian Space Research Organization (ISRO) with headquarters at Ahmedabad, created by DAE in the same year. By the middle of 1972 a separate Department of Space (DOS) and a space commission were created by the Government of India, when ISRO was brought under the new Department.

OBJECTIVES OF ISRO

The principal objectives of ISRO are: (i) application of space science and technology to further national goals in mass communication and education via satellites as well as the survey and management of natural resources through remote sensing technology from space platforms; (ii) development of space technology in India with the maximum degree of self-reliance to further the aforementioned applications in the matter of design, development, and fabrication of satellites and rocket systems with their related tests and operational facilities; and (iii) utilization of the spin-offs from developments in space research in other fields of research, industry, education, and related areas. The activities of ISRO are thus aimed at harnessing developments in space science and technology for the socio-economic progress of the country. While ongoing programmes are continuously reviewed in the light of new develop-

ments in India and abroad, basic research and co-operation with other institutions in India are fostered selectively. Attempts are being made to establish links between national and international agencies as well as developing countries that may like to send teams for training courses organized by ISRO from time to time.

The activities of ISRO are carried out at its four space centres, namely, (i) Vikram Sarabhai Space Centre (VSSC) at Trivandrum, Kerala; (ii) Space Applications Centre (SAC) at Ahmedabad, Gujarat; (iii) ISRO Satellite Centre (ISAC) at Bangalore, Karnataka; and (iv) SHAR Centre at Sriharikota, Andhra Pradesh. Given below are brief descriptions of the activities of these four centres.

Vikram Sarabhai Space Centre: Vikram Sarabhai Space Centre (VSSC), named after Vikram A. Sarabhai (1919-71), founder of the Indian space programme, is the pivotal unit of ISRO. It is responsible for research and development activities in space technology and all aspects of work related to the development of sounding rockets and satellite launch vehicles, scientific and technological payloads, ground-based and vehicle-borne instrumentation, and production facilities for propellants and rocket hardware. It has been responsible for building the ground facilities for testing and launching rockets. Under these two projects, VSSC has built and launched the *Menaka* and *Rohini* (including *Centaure*) series of sounding rockets for meteorological and scientific investigations of the upper atmosphere.

VSSC had originally run and maintained TERLS which, as already mentioned, has received UN recognition as an international facility for sounding rocket experiments with a view to investigating problems of meteorology and ionosphere over the geomagnetic equator running close to Thumba and for other experiments. TERLS is now a part of ISRO Range Complex (IREX) and has successfully launched, as on June 1984, 1,613 sounding rockets of different makes for meteorological, ionospheric, aeronomic, and astronomical studies. Scientists from Bulgaria, France, West Germany, Japan, the U. K., the U. S. A., and the U. S. S. R. participated with their Indian counterparts in many of those experiments.

SSTC is the principal research and development laboratory of VSSC. Solid propellants for rockets are produced at its Rocket Propellant Plant, while the rockets and other hardware are manufactured at the Rocket Fabrication Facility (RFF). Its Propellant Fuel Complex (PFC) produces special materials needed for the propellants. Liquid propellants for rockets have also been developed on a laboratory scale. An experimental plant for the production of ammonium perchlorate, used as oxidizer in solid propellants, has been set up at Alwaye, Kerala.

India's first satellite launch vehicle SLV-3, successfully launched on 18

July 1980 from ISRO's SHAR Centre at Sriharikota, was developed at VSSC. This four-state solid propellant rocket placed a 35-kg. indigenous *Rohini* satellite (*RS-1*) into a near earth orbit. SLV-3 had its first developmental flight on 31 May 1981 from the SHAR range. It placed a 38-kg. *Rohini* (*RS-D-1*) satellite into a near-earth orbit which was, however, lower than expected. The main purpose of this flight was to evaluate performances of the vehicle for future operational flights. The satellite carried a land-marker sensor payload. Though expected to last for ninety days, the mission ended after nine days with the satellite reentering the atmosphere due to the low performance of the vehicle. However, *RS-D-Z* satellite launched on 17 April 1983 using SLV-3-DZ rocket vehicle from SHAR has performed beyond its designed life of 100 days, having completed 250 days with a payload of a smart sensor camera that has generated 4,000 good-quality images of India's land mass.

The 22·7-metre-long SLV-3 is being augmented with strapons to achieve a vehicle (ASLV) capable of putting 150-kg. satellites into a low earth orbit. A Polar Satellite Launch Vehicle (PSLV) for putting 1,000-kg. class satellites into sun-synchronous orbits is another programme on the anvil.

Space Applications Centre (*SAC*): Space Applications Centre (SAC) is engaged in the planning and execution of the space application projects of ISRO. Its objective is to apply space science and technology to practical uses. To achieve this objective SAC has taken up work in telecommunications and television broadcasting and reception via satellites; use of remote sensing techniques to survey natural and renewable earth resources; and studies in space meteorology and satellite geodesy. It has made rapid progress with respect to the Satellite Instructional Television Experiment (SITE). A year-long experiment in direct broadcast of television programmes via NASA satellite, ATS-6, was carried out between August 1975 and July 1976. During the experiment community T.V. sets manufactured by Electronics Corporation of India Ltd. (ECIL) were installed in 2,400 villages in Rajasthan, Bihar, Orissa, Madhya Pradesh, Karnataka, and Andhra Pradesh and instructional programmes were beamed directly via satellite. To facilitate the experiment the U.S.-built ATS-6 for mass communication etc. for SITE was launched in May 1974 and then moved over to 35°E longitude on a geosynchronous altitude over the Indian Ocean.

SAC also made progress in the areas of remote sensing applications, meteorology, geodesy, and microwave engineering. A joint project by NPL with the Indian Council of Agricultural Research (ICAR) called the Agricultural Resources Inventory and Survey Experiment (ARISE) was conducted during 1974-75, employing remote sensing techniques, to assess crops and land use pattern in Anantapur district of Andhra Pradesh and Patiala district of Punjab, and valuable data were collected. A photo processing facility and an

image processing facility have been set up to analyse and interpret remotely sensed data. SAC has also developed microwave systems as well as work on satellite geodesy and meteorology.

ISRO Satellite Centre (ISAC): ISRO's satellite centre, ISAC, at Bangalore, is responsible for designing, fabrication, and integration of spacecraft and the development of satellite technology. The first Indian satellite, *Aryabhata*, named after the famous ancient Indian astronomer and mathematician, was designed and fabricated at this centre. This 360-kg. satellite was launched on 19 April 1975 into a near-circular orbit of 600 km. at an inclination of 51° to the equator from a Soviet cosmodrome, using a Soviet intercosmos rocket. The spin-stabilized satellite survived in orbit well beyond the designed lifetime of six months. All the technological systems on board the satellite functioned well. With the launching of *Aryabhata*, India acquired indigenous capability in satellite technology, namely, to design and fabricate a space-worthy system and evaluate its performance in orbit, evolve the methodology of conducting a series of complex operations on the satellite, and set up the necessary receiving, transmitting, and tracking systems, besides the establishment of the infrastructure for fabrication of satellite systems.

The second Indian satellite, *Bhaskara*, was launched on 7 June 1979 from a Soviet cosmodrome for earth observations. The 444-kg. experimental satellite, named after two ancient Indian astronomers, was designed and built by ISRO. It contained sophisticated instruments for carrying out remote sensing experiments over India using T.V. cameras and microwave radiometers. Experiments by *Bhaskara* have been useful in the fields of forestry, hydrology, snow-cover and snow-melt, geology, soils, land use, and ocean surface studies.

Bhaskara II, an improved version of *Bhaskara* satellite, with a wider scanning range, was launched on 20 November 1981 from the Soviet Union using a Soviet vehicle. The 436-kg. satellite is spin-stabilized. It carries as principal payloads two television cameras and a three-frequency microwave radiometer system. The T.V. camera data will help studies in hydrology, forestry, and geology, while the radiometer data will aid the monitoring of ocean surface state.

Rohini satellite (*RS-1*), developed at ISAC, was the first Indian satellite to be launched from India using the indigenous SLV-3 vehicle. A series of *Rohini* satellites covering selected scientific and application payloads for launch by future SLV vehicles are under development at SAC.

India's first experimental three-axis-stabilized geostationary communication satellite *APPLE* (Ariane Passenger Payload Experiment) built at ISAC was successfully orbited on 19 June 1981 by European Space Agency's Ariane launcher from Kourou in French Guyana on its third developmental flight. From an initial transfer orbit *APPLE* was placed in a 24-hour geostationary

orbit over 102° East on 16 July 1981. All the systems on board the 670-kg. spacecraft designed for conducting communication experiments in C-band functioned normally except that one of the two solar panels could not be deployed in orbit. *APPLE* has enhanced India's technological capability in building a three-axis-stabilized geostationary communication satellite. It is being used for conducting experiments in communication technology and for domestic communication, radio-networking data relay, remote area communication, etc. on an experimental basis. While the communication payloads of the satellite were built at SAC, important sub-systems like apogee boost motor and secondary propulsion systems were built at VSSC.

Space-based remote sensing of natural resources being one of the major goals of ISRO, efforts are under way to develop an operational Indian remote sensing satellite (IRS).

SHAR Centre: The SHAR Centre at Sriharikota Island in Andhra Pradesh is being developed as a range for launching bigger satellite launch vehicles like ASLV and PSLV. As already mentioned, India's first satellite launch vehicle SLV-3 was launched from here. A comprehensive test facility for conducting various ground tests of rocket motors and sub-systems has been set up at this centre. This test facility is being augmented for PSLV programme. The ISRO Telemetry, Tracking and Command Network (ISTRAC), which has been set up to manage the telemetry and telecommand network of ISRO, has supported all ISRO missions such as *Aryabhata*, *Bhaskara*, *RS-1*, and *APPLE* with its network stations at SHAR Centre, Ahmedabad, Car Nicobar, and Trivandrum. Ground support and other launch facilities in SHAR, TERLS, and Balasore Rocket Launching Station (BRLS) work collectively for IREX.

Among many other activities of ISRO mention may be made of its participation during 1979 in the Monsoon Experiment (MONEX), a regional component of an international study designated Global Atmospheric Research Programme. MONEX was conducted jointly by the World Meteorological Organization and the International Council of Scientific Unions. IMD was the main executing agency of this project in India. ISRO's contribution to the project comprised collection of wind data using rockets and meteorological data collected by using omega sondes.

SATELLITE TELECOMMUNICATIONS EXPERIMENTS PROJECT (STEP)

Under an agreement between ISRO and the Symphonie organization one of the two transponders aboard the Franco-West German Symphonie satellite was made available for Indian experiments in satellite telecommunications for two years beginning from June 1977. Known as the Satellite Telecommunications Experiments Project (STEP), this two-year project was taken up by ISRO in collaboration with the Posts and Telegraphs Department. Under

STEP, experiments in remote area communications using transportable terminals, radio-networking emergency communications, digital communications, multiple access, integration of satellite circuits into terrestrial network, and multiple audio-video transmission were conducted. The project was mainly aimed at providing a system test of geosynchronous communication satellite and developing India's expertise in the design, development, fabrication, and operation of communication systems involving geostationary satellites.

The ground network for STEP consisted of the earth stations at Ahmedabad, Delhi, and Madras; Transportable Remote Area Communication Terminal (TRACT); and the Emergency Communication Terminal (ECT).

RESEARCH IN SPACE SCIENCES

Basic research in space sciences was conducted primarily at PRL and VSSC using various rocket and satellite-borne instruments with the object of understanding the structure and dynamics of the upper atmosphere, solar-terrestrial relationships, and problems in astrophysics. A plasma-physics laboratory was set up to study the various ionospheric phenomena observed under laboratory simulated conditions. Artificial recharging of ground-water in Ahmedabad is one of the main application projects undertaken by PRL, including analysis of moon samples.

Success in space research demands united efforts of many organizations. The areas of study cover a wide variety of scientific disciplines and include meteorology and neutral upper atmospheric physics with its related area of aeronomy, ionospheric physics, geomagnetism, cosmic rays, solar planetary physics, solar terrestrial interaction, astronomy based on optical radio, X-rays and gamma rays by means of ground-based as well as rocket and satellite-borne experiments, geophysics, geocosmophysics, and archaeology-hydrology. Some of the organizations participating in this combined research endeavour are All India Radio, Delhi; Andhra University, Vishakapatnam; Banaras Hindu University; Gujarat University, Ahmedabad; Indian Institute of Astrophysics, Kodaikanal; Indian Institute of Geomagnetism, Bombay; Indian Institute of Science, Bangalore; India Meteorological Department, Pune; Institute of Radiophysics and Electronics, University of Calcutta; Kurukshetra University; National Physical Laboratory, New Delhi; Physical Research Laboratory, Ahmedabad; Punjab University, Patiala; University of Delhi; Kerala University, Trivandrum; University of Udaipur; U. P. State Observatory, Naini Tal; Vikram Sarabhai Space Centre, Trivandrum; and Tata Institute of Fundamental Research, Bombay.

INDIAN NATIONAL SATELLITE (INSAT) SYSTEM

The multi-dimensional aspect of space research and application is evident from the working of the Indian National Satellite System (INSAT). Estab-

lished by DOS in close co-operation with the Ministries of Communication, Tourism and Civil Aviation, and Information and Broadcasting, the INSAT system is a multipurpose operational space enterprise providing meteorological and television services from a common satellite in geostationary orbit. From the telecommunication point of view it is intended to provide facilities for long distance telephoning, communication with remote areas and islands, and emergency transmission of information during periods of natural calamities. From the meteorological point of view it holds out prospects of round-the-clock observation of the weather system and data collection and relay from a remote unattended platform. It is also capable of transmitting danger warnings. In the field of television it can broadcast directly from satellites to community T.V. sets in rural areas and to radio networking. The INSAT-I system is programmed to have an initial space segment comprising two multipurpose satellites in geostationary orbit at 74°E and 94°E longitude. The INSAT-IA satellite was successfully launched on 10 April 1982 from Cape Canaveral, U.S.A. This satellite orbiting at 74°E longitude was built by the Ford Aerospace and Communication Co-operation (FACC) to the specification given by DOS. It has the responsibility for the establishment, operation, and maintenance of the INSAT-I Space Segment. The Post and Telegraphs Department is responsible for the telecommunication services, IMD for the establishment and operation of meteorological ground segment and its utilization, while All India Radio and Doordarshan look after the operation of direct T.V. broadcasting. The ground segment of INSAT-I consists of five large earth stations, thirteen medium earth stations, ten remote area terminals, and three road-transportable/airliftable communication terminals. The Master Control facility for INSAT satellite is located in Hassan district of Karnataka. It consists of two satellite control earth stations and a spacecraft control centre. The launch and associated services for INSAT-I system are being obtained from NASA on cost reimbursable basis according to an agreement made in November 1980.

CONCLUSION

Space technology in India has already established the capacity of high-quality research, design, and development in all the fields of space engineering like aeronautics, avionics, and electronics as well as in the processing and manufacture of sophisticated rockets and satellites. The expertise can be used for development and fabrication of large booster rockets to launch application satellites mainly for down-to-earth use. The space applications will further endeavour to utilize the support of space technology and science for solving some traditional problems faced by this country with a vast rural population so long deprived of the benefits of a modern space age. The whole concentra-

tion of space application is on the major areas of satellite communication including SITE type satellites, remote sensing of natural resources for detection/prediction of problems and prospects associated with fields such as agriculture, minerals mining, meteorology, and geodesy. The whole range of ISRO activities is tuned towards this goal. One of its two latest achievements was the launching of INSAT-IB in 1983 with the help of spaceship *Challenger* from Cape Kennedy in the U.S.A. The other was its collaboration with the U.S.S.R. involving an Indian in a week-long joint space flight with two Soviet cosmonauts to the SALYUT-7 space station, which ended successfully on 11 April 1984.*

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—*Author*

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DEFENCE RESEARCH

DEVELOPMENT of science has tremendously affected military technology all over the world during the last half century or so. The impact has not, however, been uniform everywhere because of uneven progress in science. Improvement in military technology came about first in a few countries where major breakthroughs in science had taken place. This induced others, particularly those which had a strong science and technology base, to formulate national defence policies with a view to attaining self-sufficiency in military equipment and thus becoming independent of pressures from nations in command of improved military technology and hardware. We see such policies being followed in France immediately after World War II, in China after 1949, and later in countries like Sweden, India, Brazil, and Pakistan. Each is developing its own technology based on both indigenous and borrowed research findings. Such indigenous efforts are fed into the industrial system to enable it to produce high technology-oriented military hardware.

The creation of such a technology-oriented military industrial complex in its turn has impact on the scientific, social, political, and economic systems of a country. They have to be kept in view in designing suitable policies for the development of such a technology-oriented military industrial complex. In this context, it may be noted that while the efforts of the Government of India were aimed at building a sound scientific research and development base, interest in defence technology grew much later. Unlike most of the countries mentioned earlier, defence research and development in India remained at a somewhat low key even after independence. This was due mainly to India's firm faith in the ideals of peaceful co-existence of nations and settlement of international disputes by negotiation and co-operation. She was not, therefore, keen on either setting up a large military machine or its concomitant defence-oriented research and development. Nor did she encourage any modern armament industry in the country. Previous to 1958, the mood of the country was concerned for economic growth, and investment in military technology had no priority. Available resources were deployed chiefly for the priority sectors and to some extent on development-oriented and fundamental researches. This resulted in minimal investment in defence research and development. The limited political objectives of the nation further strengthened this position of the Government and there were no pressures for urgency in defence development. Besides, investment in defence industry was considered largely unproductive.

The political philosophy of Nehru that resolution of international conflicts and problems should take place through political processes generally reinforced this low-key defence posture.

The needs of defence first began to be felt around 1958 when the Scientific Policy Resolution came into force. Two factors influenced the Government's decision. Firstly, the cost of importing and maintaining armament and equipment was becoming increasingly high. Secondly, the foreign exchange required for such purposes was scarce. These factors, amongst others, led to the creation of the Defence Research and Development Organization (DRDO) in 1958. DRDO brought together some of the technical development esatblishments of World War II, started new laboratories, and began developing operational research programmes in the newly-created Defence Science Laboratory. Investigations on some of the hardware problems of the Army were also taken up. D. S. Kothari was designated Scientific Adviser to the Defence Minister and was mainly instrumental in structuring and giving direction to this new organization. Under him was appointed a Chief Controller of Research and Development (CCR & D). The headquarters of the organization was located in the Ministry of Defence to facilitate co-ordination of the efforts of the laboratories under DRDO and for liaison with the Defence Ministry and the armed forces headquarters. S. Bhagavantham, who succeeded Kothari in 1962, created several new laboratories covering, amongst other things, aeronautics, missiles, metallurgy, electronics, and radar. The organization (DRDO) was placed under the Minister of Defence Production to link it closely with the production agencies like ordnance factories and the public sector defence industries, viz. Hindustan Aeronautics Limited, Mazagon Docks Limited, Bharat Earth Movers, and Bharat Electronics Limited. B. D. Nag Chaudhuri succeeded Bhagavantam in 1970. The armed conflict with Pakistan in 1971 and the difficulties of getting imported military hardware underlined the importance of indigenous technology capable of yielding quick results in several crucial areas. The headquarters structure was strengthened by introducing three CCR & Ds tolook after separate sectors like missiles and aircraft, engineering and technology (electronics, guns, tanks, etc.), and scientific disciplines including chemicals, operations research, physiology, and nutrition. A Joint Secretary was to manage the administrative link with the Ministry of Defence. Scientific Advisers were also placed with the Army, Navy, and Air headquarters with a small staff of their own to give immediate help at the armed forces headquaters and, in case of necessity, to draw from the rest of the Defence Research Organization. Scientific Advisers were also placed with the various commands. M.G.K. Menon succeeded Nag Chaudhuri in 1974.

The Scientific Adviser to the Defence Minister is also Director-General of the Defence Research and Development laboratories, being responsible for

co-ordinating the work of the various research and development establishments of the Defence Ministry. He is also a Secretary to the Minister in charge of defence research.

Trend of Expenditure: The defence research and development expenditure was quite trivial in the period between 1947 and 1958. There was no separate budget for defence research and development, but small sums were made available from the budgets of the ordnance factories to the technical development establishments which amounted to two to three million rupees in 1948. The expenditure rose gradually over the years due to the pressure of various needs of maintenance, repair, and production in the ordnance factories. In 1958-59 this budget was consolidated and increased to Rs 20 million as the initial budget of the newly-constituted DRDO. In relation to the total national expenditure on research and development, this was at that time around 5·4 per cent. In relation to the total national expenditure on research and development the expenditure on defence research and development has fluctuated since 1965 between 10% and 15%. In 1979-80 the expenditure on defence research and development was Rs 984·6 million as against an estimated expenditure of Rs 6,296·7 million on national research and development projects. The former thus constituted about 15% of the latter. In real terms, however, the expenditure has not grown to the extent the figures imply as they have not been corrected in each case to the prevailing buying power of the rupee. The devaluation of the rupee as well as the inflationary situation in the country during the entire period, and particularly from 1965 to 1973, had eroded the buying power of the rupee substantially and, therefore, the resources made available were considerably smaller in real terms.

The initial efforts of DRDO were related to certain felt needs. For example, the high altitude, desert, and jungle areas in the frontiers of the country created problems of how human beings and equipment would react to these conditions and what could be done to make the soldiers and equipment more adapted to these rather special environments. There was also continuing effort to improve conventional armament and equipment to meet these varying environmental conditions. The problems of snow, avalanches, and adaptation of vehicles for performance at high altitudes and desert areas were initially taken up for research to meet the needs of the armed forces. After the conflict with China in 1962, many deficiencies in equipment and logistics were detected and the programmes of defence research and development were accordingly expanded with higher expenditure. In 1965 there was a border conflict with Pakistan. During this conflict Britain and the U.S.A., main suppliers of armament and equipment for the Indian armed forces, decided to stop supplies. The Government of India realized the precarious state of the nation having to depend largely on foreign supplies for its armed forces to pursue its own independent

national policy. It became clear that India might face very difficult situations in the future because of her dependence on the goodwill of supplying nations and their variable political assessments. This could influence their attitude and make them modify or go back on their commitments or refuse to make new commitments. This might happen with changes in the local political situation or the regional international situation or due to changes in the Indian situation. Accordingly, the Government of India decided to increase the rate of growth of expenditure on defence research and development in order to encourage manufacture of a large variety of sophisticated equipment and weapons needed by the armed forces. New programmes of development in armoured vehicles, electronics, guns, and gun-sights were taken up. The difficulties of getting military and quasi-military supplies during and after the conflict with Pakistan in 1971 further sharpened the view that foreign sources of armament could be vitally affected in critical political and military situations. These experiences created the awareness of urgency for a high degree of self-reliance in armament and equipment as well as in spares and components for their maintenance to cope with any operational situation. The defence research and development effort was expanded further and work in areas like radar, aeronautics, and missiles was intensified. Shortage of foreign exchange restricted the ability of the Government to purchase military equipment and armament from abroad, leading to efforts for their indigenous development and manufacture. Initially, indigenous effort involved a larger expenditure of foreign exchange due to the necessity of importing much of the machinery and facilities for production, research, testing, and evaluation.

The defence research and development expenditure of the country has slowly increased. This increase has been more or less in keeping with the national research and development expenditure and not out of step with it. In comparison, in most countries with a fair involvement in defence expenditure, the defence research and development expenditure shows variations in the range of twenty to fifty per cent, and even more in some cases, of their total research and development expenditure. In the case of India, the ratio of expenditure on defence research and development to the national research and development is still far from it. The defence research and development expenditure as a fraction of the total Gross National Product (GNP) has increased from 0·23 per cent in 1958-59 to 0·64 per cent in 1980-81.

The relatively small magnitude or low profile of the total defence research and development effort in the national system does not mean it is either negligible or without relation to other areas of national scientific effort. On the contrary, it indicates that DRDO has developed as a part of the national scientific effort freely inducting scientists into its laboratories for short and long terms from other areas, and conversely providing scientists from the

defence organizations to other research organizations, industries, and universities. This policy of free flow of scientific personnel to and from the defence research establishments is deliberate and has brought about closer liaison within the entire scientific community of the country. The Defence Science Organization (DSO) does not normally finance substantial research programmes in research institutions and universities. However, if there are investigations or development work on techniques of defence interest in research institutions or universities, it sometimes gives additive funds mainly to increase the speed of work or to obtain special equipment which was not easily available.

Technological efforts in defence research created various pressures and enlarged or reconstituted their objectives. Actual experience of the armed forces during the conflicts with China and Pakistan also presented new problems. The Arab-Israel conflicts of 1967 and 1973 as well as the Vietnam war had their lessons for our armed forces and the Defence Ministry. The experience of various difficulties in obtaining military hardware and even ancillary equipment from abroad due to the unwillingness of foreign suppliers influenced the planning of the armed forces as well as the Defence Ministry as it did that of DRDO.

There were other technological constraints. Sophisticated hardware had to stand rough use and had to be maintained, repaired, and even improved in the field. These constraints underlined the need for developing a technological base within the country's own defence sector in keeping with its overall research and development effort. It was realized that the basic technological standard outside defence was the infrastructure on which defence technology had to be built.

As research in the defence laboratories began to grow, a gap emerged between their developing technologies and the capacity of our industries to absorb and use them in production. It was soon discovered that development in defence science could not be carried out in total isolation from either the rest of the scientific community or the concerned industries within the country. Due to the elementary constraints of military reticence, the personnel of defence research establishments are bound to work in some degree of isolation. But in India the danger inherent in increasing isolation of the defence scientific community from the broader community has been recognized to some extent with the result that projects and research programmes as well as training programmes related to defence have been given to the Indian Institute of Science and the Indian Institutes of Technology. These establishments have become probably the most significant suppliers of trained manpower for defence. They also carry out development research in a large way in some of the basic areas of interest to military science. A small bridge between the defence science community and the rest of their colleagues has thus been provided. These

trends of internal interactions have encouraged the growth of technology and have reinforced the movement towards self-reliance in defence. India's posture of non-alignment has helped this process further. We are trying to learn gradually that technological self-reliance is a necessity growing out of the policy of non-alignment.

The increase in defence research and development efforts has been steady since 1962. It has, however, been marked by an attempt to contain defence expenditure within the framework of national priorities, simultaneously recognizing the growing sophistication of military equipment and the technological means of defence. With the growth of defence research and development efforts two benefits have accrued. Firstly, the defence system has become more capable of adapting for its own purposes various spin-offs from civil research and industry. Secondly, in more recent times, the opposite also has happened—there have been spin-offs from defence research, development, and industry which have been used effectively in civil sectors. While these phenomena are well known in the developed countries like the U.S.A., U.S.S.R., U. K., Germany, or France, such examples of inter-sector exchange of scientific and technical know-how in India even in a limited range demonstrate the indivisibility of science within a nation and the necessity of having close linkage between civil and defence scientific efforts. The scientific effort in defence has also recently been strengthened to meet the needs of a viable defence posture.

Funds for Defence Research: Funds for defence research pose no problem to the national exchequer since they represent only a small fraction of the total research expenditure of the country. In 1980-81, for instance, the expenditure on defence research and development organizations was Rs 830 million as against an estimated expenditure of Rs 7,261 million on research and development as a whole. Further advantages might accrue to defence, however, if there were stronger linkages between defence and civil research. The optimization of the results of national research and development effort requires not only much closer co-ordination between civil and military sciences, but also closer techno-economic analysis to choose between alternative strategies and technologies. There are, however, strong reasons to avoid too close a linkage between civil and military sciences because of various political considerations. At any rate, there has not been any significant mobility between the defence research scientists and scientists in other scientific establishments in spite of the fact that the salaries or privileges of the two categories are more or less the same.

A major problem in scientific effort in any area, but crucial in the defence sector, is that research or development work cannot be switched on and off as one wishes. A new model of aircraft or tank takes about ten years to be developed and brought to the stage of production. Scientific and technological effort has thus to be sustained over a long period in a particular direction.

Transfer of Know-how: Transfer of know-how from the laboratory to the factory is a problem which concerns not only defence but the entire area of developmental efforts. It is in fact somewhat less acute in defence production because of the strong hardware-orientation that scientists in the defence sector receive quite early in their careers. The Ministry of Defence at various times in recent years has tried to find partial answers to this problem of linking defence research and new military hardware production through various administrative devices. But basically, the problem persists because the laboratories and establishments have no expertise or understanding of the technology and economics of production, and our industries have no engineering experience in translating concepts, laboratory models, and monotypes into production technology. Further, the industrial system and the Governmental system of running research laboratories and institutions have very little in common in either outlook or skills or management styles so that even a dialogue is sometimes difficult.

There is another group of problems which arise from the fact that India has yet to develop a technology-oriented military system. In a military organization, social isolation is sought, created, and preserved. There is a concern about rank, hierarchy, discipline, ceremonials, and other behaviour patterns. In a technology-oriented organization achievement becomes more important than competence; the job becomes more important than rank, and success in the field more important than the spit and polish of the barracks. These inherent differences in outlook and behaviour have not changed in spite of the massive input of technology during the last thirty years. In several countries, however, technological and social changes have brought about changes in their military organizations. The military set-ups in some of them have become specialized, socially and institutionally, besides being technologically oriented. However, such changes do not come about easily in any organization, particularly in a traditional military set-up.

One thing in favour of India is that her armed forces are voluntary and not conscripted. The high sense of involvement and loyalty required to carry out such a drastic orientation of behaviour pattern and work motivation come more easily to a voluntary force. Moskos, a military sociologist, has observed that the involvement and loyalty required for accepting large changes is not readily available in a conscript force and should be easier to establish in a voluntary force. The sociological advantages in a voluntary army have not been fully explored in our country. These sociological factors can be exploited to develop a greater striking power of our armed forces within the same physical parameters. The armed forces in any country have other responsibilities assigned to them. These also require training and structuring of the forces in a flexible manner. For example, an army may be called on to perform a

variety of non-military functions such as peace-keeping, looking after the security of the borders, and rescue operations during floods and other national calamities. A modern voluntary army can serve a very large variety of national purposes and needs. To do so, it has to deliberately develop a high degree of loyalty and involvement and develop its non-military potentials through a rigorous technical and social training to enable it to undertake, when needed, civil, technological, and quasi-military tasks.

The complexity of modern technology and consequently of economic, social, and military relationships that a modern armed force has to deal with has led to various sociological studies of the military system in several countries. These sociological and socio-technological studies have been used in the modernization programmes of the armed forces and their continual upgrading the world over. Moskos and other sociologists, who have studied the advantages and disadvantages of the voluntary versus the conscript armed forces, have pointed out that voluntary armed forces have many advantages in a modernized military system. Moskos has compared the modern technologically-oriented military systems with the modern industrial systems, particularly in the context of the worldwide trend towards socialism. He and others like him have tried to show that the effectiveness of a modernized military system can be much greater than that of the traditional hierarchical patterns of the inflexibly structured and highly centralized armed forces. The growth of defence research and military technology has to be supported by a high standard of industrial expertise. The future of the Indian armed forces in general and defence research in particular is thus dependent on the overall development of science and technology in this country.

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